Design review of
West Bengal Pollution Board office building
Salt Lake, Calcutta

Final Report

Submitted to

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by

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Executive summary

The lighting design of an office should be considered early in the design stage to enable a possibility of daylight integration. It is possible to make changes with the artificial lighting design in the post construction phase relatively easily, but significant changes to the day lighting are very much more costly and difficult; although they may be cost effective in the long run. Daylight within an office space has a major effect on the appearance of the space, and can have considerable energy efficiency implications. Building occupants generally prefer a well daylit space, provided that problems such as glare and overheating are avoided.

The major factors affecting the day lighting of an interior are the depth of the room, the size and location of windows and rooflights, the glazing system and any external obstructions Appropriate planning at an early stage can produce a building which will be more energy efficient as well as having a pleasing internal appearance. Appropriate planning at the early stage would involve proper fenestration and shading design. It is usually wise to start by calculating the area needed for good dayligting (unless the space is too deep), trimming it if necessary to control fabric heat loss in winter & solar gain in summer

Levels of indoor daylight are usually specified by daylight factor (DF). Based on recommended DF on work plane, the required glass area is determined. Having determined a target area of glass, a designer has to choose the shape and position and the outcome is likely to be a conflicting requirement for view, avoidance of glare, even spread of daylight indoors, and thermal aspect. In a well daylit building, daylight often provides sufficient illumination for activities such as circulation for the majority of the day and can provide adequate working light for the entire year. However, to utilise fully the benefits of daylight in an interior, it is important to ensure that the electric lighting is turned off when daylight provides adequate illumination. This is achieved by the use of appropriate lighting controls and may involve some degree of automation.

The basic aim of the study conducted for the West Bengal pollution control board office building was to design fenestration and shading devices in order to provide optimum visual and thermal comfort.

Six basic cases of window/shading combinations were considered and analysis for each of the cases in all areas were made. The various cases considered were:

Case (1) **Proposed window and proposed shading**

This is the base case for analysis with window and shading devices as designed by the architect.

Case (2) **Proposed window & modified shading**

In this case, the window sizes are as designed by the architect but the shading devices have been modified as per CBRI recommendations.

Case (3) Modified window & proposed shading

Modified window is the one with top light removed and the rest of the window is the same as in the proposed case, the shading remaining as proposed by the architect.

Case (4) Modified window & modified shading

In this case the window is the one with top light removed and the shading device is as per CBRI recommendations.

Case (5) Recommended window & proposed shading

This window has been designed to provide daylight as recommended by the Central Building Research Institute (CBRI) and the shading remains same as proposed by the architect.

Case (6) Recommended window & recommended shading

This window and the shading device have been designed to provide daylight as recommended by CBRI.

Based on the recommendations suggested by TERI, the architect came up with a final design which adopted the recommendations partially This was then analyzed for visual and thermal efficiency.

Finally, in the north facing laboratory, the window sizes are 3.00 × 1.2 m and the roof light sizes are 3.00 × 0.5 m. The projections have not been changed and have been retained at 0.5 m for the windows and for the top lights it is 0 9 m. The south facing windows have been resized to 3 × 1.2 m and the top lights have been retained and resized to 3 × 0 5 m The recommendations suggested removal of top lights In the office block the windows were resized to 3 × 1.2 m and 3 × 0 5 m and on the east face slit windows with inclined louvres were introduced. For the other faces the shading devices were kept at 0.5 m for the windows and 0.9 m for the top lights.

The artificial lighting was designed using a software with 2 × 36W Trulite from Philips in a batwing mirror optic luminaire. 36W Trulite gives 30% more light output than standard 36W fluorescent tubelight. Batwing mirror optic luminaries are designed to direct the light from the lamps in the required direction. These allow fewer lamps and luminaires to be used to produce a given illuminance. For effective utilisation of daylight for energy efficiency, appropriate lighting controls need to be incorporated. Timers to switch on & off a specified group of luminaires was the most appropriate control option for the laboratory spaces. The lighting levels at the specified grid points were determined using a standard lighting software. Then the day lighting and supplementary lighting levels were superimposed to decide on the lighting control strategy.

The levels of visual and thermal comfort and the savings achieved are given in the tabular format as below:

Table 1. Lighting levels and cooling load on a typical floor

Area	Case	Lighting levels	HVAC load		Zone temperature
			Peak load	Avg. Load	
North facing lab	Proposed window/shading	480 lux	8.5 KW	8.1 KW	-
	Recommended window/shading	270 lux	8.0 KW	7.6 KW	-
	Final design	340 lux	7.5 KW	7.0 KW	-
South facing lab	Proposed window/shading	610 lux	4.2 KW	4.0 KW	-
	Recommended window/shading	305 lux	4.0 KW	3.8 KW	-
	Final design	460 lux	3.9 KW	3.7 KW	-
Office block	Proposed window/shading	880 lux	-	-	36.0°C
	Recommended window/shading	250 lux	-	-	34.7°C
	Final design	480 lux	-	-	34.9°C

Table 2. Consumption and savings on a typical floor

Area	Case	Lighting consumption	HVAC consumption	Total consumption	Saving
North facing lab	Proposed window/shading	5070 kWh	11592 kWh	16662 kWh	-
	Recommended window/shading	5070 kWh	10944 kWh	16014 kWh	3.9 %
	Final design	936 kWh	10080 kWh	11016 kWh	33.9 %
South facing lab	Proposed window/shading	2150 kWh	5760 kWh	7910 kWh	-
	Recommended window/shading	2150 kWh	5472 kWh	7622 kWh	3.6 %
	Final design	624 kWh	5328 kWh	5952 kWh	24.7 %
Office block	Proposed window/shading	12960 kWh	-	12960 kWh	-
	Recommended window/shading	12960 kWh	-	12960 kWh	-
	Final design	5610 kWh	-	5610 kWh	56.7 %
One typical floor	Proposed window/shading	20180 kWh	17424 kWh	37608 kWh	-
	Recommended window/shading	20180 kWh	16416 kWh	36596 kWh	2.5 %
	Final design	7170 kWh	15408 kWh	22578 kWh	39.8 %

The consumption (lighting , HVAC and total is measured annually assuming nine working hours per day and five working days per week).

The total saving achieved by controlling window sizes/shading devices is approximately 39.8%.

However, the Architect has already employed solar passive techniques with respect to orientation and depth of plan. This in itself has led to a saving of about 2.6% over a conventionally designed building.

Hence, combining the techniques of correct orientation, depth of plan, window and external shading, it is anticipated that the designed Pollution Control Building at Salt Lake will save approx. 41.5% energy annually over a conventionally designed building of the same size.

CHAPTER 1

Energy efficient lighting and thermal comfort

Introduction

The world is becoming increasingly aware that in the not too distant future, energy will become a scarce and expensive commodity. And this in turn might effect the economic development in the future Almost all the important cities in India are experiencing an unprecedented period of growth which has created an ever increasing demand for energy Urban population has become painfully familiar with the problems of obtaining adequate supplies of electricity, diesel and other forms of energy inputs Architects and building designers who design different types of buildings for different use are also aware of this fact They know that the buildings they design in order to provide adequate visual and thermal comforts consume energy in lighting and space conditioning systems. In India, in an air-conditioned office, the energy consumption in lighting is comparable to that for air-conditioning. In 1992, the total electricity consumption in commercial sector in India was 21.6 billion kWh in which lighting and HVAC consumptions accounted for approximately 60% and 32% respectively Architects and designers have understood now that conservation is one means which could be used very effectively to help match energy supply with demand. With growing awareness they feel that there is an urgency to do something positive and find that the immediate challenge for them to design energy efficient building envelope coupled with energy efficient building energy systems.

Energy efficient lighting

Good lighting in a building provides sufficient light in the right place at the right time. This enables the occupants to see easily and in comfort allowing them to perform their work efficiently without strain or fatigue. In addition, good lighting enhances the appearance of a space to provide a pleasant internal environment and can contribute to the creation of different atmospheres appropriate to different activities.

Electric lighting in commercial buildings is a substantial energy consumer and represent a significant cost. Its energy consumption depends on the installed load and the hours of use of the installation. The installed lighting load depends on the quantity of light to be provided in the building and the type of lighting equipment to be used. The hours of use of a lighting installation depend upon the occupancy patterns of the space, the daylight available in the space and the control system used.

A lighting system is energy efficient if it requires the minimum use of electricity to produce the desired standard of services. Hence, the design of energy efficient lighting system ensures that both these aspects of lighting standards and minimum use of electric energy are carefully considered.

Energy-efficient lighting techniques

In order to achieve the maximum benefits from the energy efficient lighting system, the lighting design should be considered early in the building design stage itself, when major decisions affecting the day lighting can be easily made

The energy efficiency of a lighting installation depends on

- the quantity of illuminance to be provided for an application
- the efficiency of various components of the systems e.g. lamp, luminaire and ballast
- the way in which lighting installation used, often strongly influenced by the control system, and the availability of daylight, and
- the maintenance regime

While planning a new installation all the above factors are judiciously considered together including the features of good lighting design The recommended values of illumination of different areas in buildings are given below

Table 1.1. Recommended values of illuminance

Buildings	Area/Activity	Recommended illumination(lux)
Home	Kitchen	200
	Bathroom	100
	Stairs	100
	Workshop	200
	Garage	70
	Reading (casual)	150
	Homework & sustained reading	300
Offices	Entrance hall and reception area	150
	Conference room, executive office	300
	General office	300
Drawing Offices	General	300
	Boards and Tracing	450
Laboratories	General	300
Libraries	Shelves, Stacks	70 to 100
	Reading tables	300
Hotels	Entrance Halls	150
	Reception and accounts	300
	Dining rooms (tables)	100
	Lounges	150
	Bedrooms	100 to 200
	corridors	70
	Stairs	100
	Bathrooms	100
	Laundries	200
	Kitchens	200

Lamps

The popularly used light sources are incandescent (GLS), fluorescent (TL), mercury vapour (HPL), metal halide (ML), high pressure sodium (SON), and low pressure sodium (SOX). Except for incandescent all the other light sources can be termed as gaseous discharge sources. The final selection of lamp for a particular type of task and place depends on the following lamp characteristics :

Lumen Efficacy

Lumen efficacy describes visible light output in relation to power input and expressed in lumen per watt. Lamps with higher efficacy value are more energy efficient than the lamps with lower values. The efficacy of incandescent lamps are in the range of 8 to 17 lm/W whereas the efficacy of fluorescent lamps lies in between 50 to 104 lm/W.

Colour Rendering

Colour rendering is a measure of the ability of the light source to show colours, and based on a colour rendering index, R_a. The R_a index is based on a scale 1 to 100, where 100 provides the best colour.

Colour Temperature

Colour temperature is a measure to describe the quality of a light source by expressing the colour appearance correlated with the black body locus Colour temperatures of 4000K or higher appear white and cool, colour temperatures of less than 3000K have a warm colour appearance.

Table 1.2. Lamp Characteristics

Lamp type	*Efficacy (lm/W)*	*Colour rendering (R_a)*	*Colour appearance (CCT)*
Incandescent (GLS)	8 to 21.5	100	2800 K
Halogen	10 % higher than comparable GLS	100	2800 to 3200 K
Fluorescent (TL)	63 to 96	< 80 to >90	2700 to 6500 K
Metal Halide	58 to 80	65 to 92	3000 to 5600 K
High Pressure Mercury (HPL)	36 to 60	15 to 52	3400 to 6000 K
High Pressure Sodium (SON)	69 to 140	23 to 60	1950 to 2500 K
Low pressure mercury (SOX)	67 to 172	None	Yellow

A lamp which has high lumen efficacy and good colour rendition is usually selected for lighting installation. A wide range of compact fluorescent lamps (CFLs) is now available that are particularly designed to replace tungsten lamps. The main advantages of using CFLs are that the comparable total light output from a CFL scheme may be obtained for only 20 - 30% of the wattage required using tungsten lamps and also the maintenance cost gets reduced due to their long rated life (almost eight times more than that of GLS). In case of fluorescent lamps, 26mm diameter slim tube lights of 36 W are now replacing 38 mm diameter tubes of 40 W in new installation. These slimmer lamps produce approximately the same light output as the larger diameter lamps of the same length and colour, but consume 8% less electricity. The tungsten spot lights are generally used in display and accent lighting. A wide range of halogen lamps are now available, and these can be used effectively thereby reducing the energy consumption by 50%. There is an increasing range of metal halide, SON lamps available in the market. These are high wattage lamps with large light outputs and are particularly useful for lighting large and high areas. Their high efficacy produces an energy-efficient solution. They are useful for exterior lighting, car parks, and floodlighting.

Ballasts

Discharge lamps require ballasts to control the lamp which in turn corrects the power factor Traditionally, the ballast consisted of a wire-wound choke, with energy losses approximately 15-20% of the total energy consumption in such control gear New design of low-loss ballast (good quality) have been developed, where the wire-wound chokes are designed for greater energy efficiency Energy savings of approximately 20% can be achieved for fluorescent lamps operated with high frequency electronic ballasts. The efficacy of a fluorescent lamps increases at high frequency, and so the energy savings result partly from this and partly from the reduced energy losses in the electronic ballast itself. High frequency electronic ballasts impose softer starting conditions on the lamps that are likely to lead longer lives thereby reducing maintenance costs.

Luminaires

Luminaires primarily have two functions: protecting the lamps and ballasts from dirt and mechanical damage, and direct the light to useful areas. Innovations in designing have increased the efficiency of the luminaires considerably Carefully designed reflector systems are used to direct light from the lamps to the desired direction thus allowing fewer lamps or luminaires to produce a given illuminance. Luminaires with diffusers or prismatic panels mainly to control glare reduce light output and are less efficient as compared to luminaires with reflectors which not only control the glare adequately but also handle the light output efficiently.

Day lighting

Day lighting within a building has a major effect on the appearance of space and can have considerable energy efficiency implications. It is variability and subtlety of daylight which is more pleasing to the occupants in contrast to the relatively monotonous environment produced by artificial light. Windows and skylights which admit daylight into a building, keep the occupant in contact with the outside world by offering an alternative long-distance view which is relaxing to the eyes. It is claimed that exposure to natural light have a beneficial effect on human health. Day lighting is important particularly in commercial and other non-domestic buildings that are functional during the day

A good day lighting system has a number of elements, most of which must be incorporated into the building design at an early stage. This can be achieved by considering the following in relation to the incidence of daylight on the building:

- the orientation, space organisation, and geometry of spaces to be lit.
- the location, form, and dimensions of the openings through which daylight will pass.
- the location and surface properties of internal partitions which reflect the daylight and play a part in its distribution
- the light and thermal characteristics of the glazing materials

Daylight Factors

Daylight entering a room is made of three components-light coming directly from sun, sunlight received from the sky, and light reflected from the ground and other exterior surfaces. The distribution of light within the room, the position and characteristics of glazing, and internal reflection. Because the exterior illuminance is variable, the day lighting of a room is characterized in terms of a parameter known as daylight factor (DF). Daylight factor (expressed as a percentage) is the ratio of the illuminance at a given plane due to the light received from the sky of known illuminance distribution to the illuminance on the horizontal plane due to an obstructed hemisphere of the sky The contribution of direct sunlight to both illuminance is excluded however, the glazing and dirt effects are included. The DF has three parts: Sky Component (SC)· The direct component resulting from the light coming directly from the sky, Externally reflected component (E.C.): The component resulting from light reflected from outside surfaces and, Internally reflected component (IRC) . the component resulting from reflections within the room.

Hence $DF = SC + EC + IRC$

Design Sky

A knowledge of daylight availability and the distribution of light in the sky is necessary for arriving at a design basis. The amount of daylight available in the open varies with the transit of sun from morning till evening as well as with the condition of the sky from season to season at a place. This necessitates the evaluation of some rational design basis which holds good for most of the working hours without proving to be an over design.

In tropics the sky conditions are mostly clear or partially clear and there is a considerable amount of sunlight incident on the ground and most building facades. This is in contrast to overcast sky conditions adopted for design in Western Europe. Based on extensive measurements of daylight availability in India, a clear sky opposite the sun for a solar altitude of 15° has been standardised as the design sky. The outdoor design sky illumination on a horizontal plane is 8000 lux. From the knowledge of sky luminance distribution and daylight availability outdoors, it is possible to calculate daylight at any point indoors through a given set of windows. Day lighting design of windows based on the clear design sky holds for about 90 percent of the working hours.

Design of Windows

Design of windows is important, as it greatly influences the indoor environmental conditions The functions of windows are to provide a view outside and to admit daylight and breeze. Glass being transparent is quite suitable for enabling a view outside and admitting the daylight. But since glass is transparent to short wave solar radiations and opaque to longwave radiations it can bring in excessive solar heat and retain it indoors. Therefore, the windows have to be so designed as to exclude solar heat in summer and admit it in winter. The provision of windows in suitable orientation from the consideration of solar incursion and wind direction is very important. A suitable orientation also helps, in achieving better thermal conditions indoors. Ventilation being relatively less affected by slight changes of orientation up to 300 from normal to the wind direction, the more critical factor is solar heat. Long axis of a building along EW with windows on longer sides facing north and south provides advantage of solar heat in winter while minimising it in summer. This orientation is, generally, suitable from ventilation point of view for most part of the country Also, the shading devices required for north and south facing windows are simpler than those required for other directions Wherever a compromise is to be made in regard to orientation due to site conditions the long axis of the building may be tilted towards NE-SW direction.

Heat gain in summer and heat loss in winter through windows is proportional to the glass area. Hence, a minimum of glass area need to be provided for satisfying the daylight requirements and a good part of this glass area should be openable for allowing in the flow of outdoor breeze in non-conditioned buildings. The recommended values of sill height for offices and residential buildings are 1.0–1.2 m and 0.9 above floor level. Window height of 1.2 m or more is desirable for providing a good penetration of daylight indoors.

Recommended Daylight Factors for Fenestration Design

Task illuminance for day lighting design is expressed in terms of percentage of the outdoors design illumination which is 8000 lux for a clear design sky in India. Hence 1% daylight factor corresponds to 80 lux. Recommended DF for typical building interiors are given below:

Table 1.3. Recommended DF for Typical Building Interiors

Area		Daylight factor (%)
Dwellings		
	Kitchen	2.5
	Living room	0.63
	Study room	1.9
	Circulation	0.31
Schools		
	Class room	1.9 - 3.8
	Laboratory	2.5 - 3.8
Offices		
	General	1.5
	Drawing, typing	3.75
	Enquiry	0.63 - 1.9
Hospitals		
	General wards	1.25
	Pathological laboratories	2.5 - 3.75
Libraries		
	Stack room	0.9 - 1.9
	Reading room	1 9 - 3.75
	Counter area	2.5 - 3.75
	Catalogue room	1 9 - 2.5

Shading devices

As mentioned in the earlier section daylight entering in building is nothing but the diffuse light through the windows provided with louvers to cut the incursion of the direct sunlight. External shading devices in form of louvers not only control the glare but also reduce the solar load on the buildings Three types of louvers mainly horizontal type, vertical type and egg-crate type (a combination of horizontal and vertical types) are generally used in practice depending upon the orientation of the windows. For north facing windows, vertical louvers normal to the wall, capped by a horizontal member of the same width on top are adequate enough to provide the required shading. Windows facing south are generally shaded with horizontal louvers. These horizontal louvers should extend much beyond the window, possibly to other windows at the same level, to avoid sunlight coming partly from the corners However, instead of extending the horizontal members to any distance beyond the window on either side, two vertical louvers may be provided at the two extremities. The vertical louvers can be either rectangular or triangular. For windows oriented east/west, the recommended shading device is a combination of horizontal and vertical louvers. The horizontal louver should be normal to the wall but the vertical louver should be inclined at 30° towards the south away from the normal to the wall. This has the advantage of letting in the winter sun during early mornings on the east facade and late evening on the west facade, and also of completely cutting off the summer sun from morning to evening. For windows facing north-east/north-west either vertical or horizontal type can be used. The vertical louvers capped by a horizontal louver of the same width will cut-off all summer and winter sun completely whereas the horizontal type of louvers will cut-off direct sun only after 7 am throughout the year.

For windows facing south-east/south-west only egg-crate type louvers can shade adequately. The recommended louver system comprises a vertical louver inclined at 30° to the normal of the wall towards south and a horizontal louver normal to the wall. This system has the advantage of intercepting all summer sun and permitting winter sun up to around mid-day on the south-east, and late afternoons on the south-west facades.

Thermal comfort and architecture

Improved thermal comfort, lesser running costs and better environmental adaptations are some of the reasons why energy efficient building design should be advocated.

In practice, however, aspects related to energy savings are not widely integrated into the building designing process. Building industry being one of the most energy intensive sectors, should resort to 'Bio-climatic architecture' in order to optimise energy use both during construction as well as in operation and maintenance. With the progress made in the technologies related to materials of construction, lighting, ventilation and air conditioning systems — architects, engineers and practitioners involved in building projects have a tendency to rely more on these systems rather than having a better grasp of the thermal aspects of the building design.

Strategies for energy efficient building design only in a warm humid climate (West Bengal) have been dealt within this chapter.

Understanding basic parameters

A basic understanding of the parameters which interact between the building and its surrounding is essential to better appreciate their role and importance in the building designing process for the different climate zones which can be typically classified into five groups: cool, temperate, hot-arid, warm-humid and composite. These parameters include the following.

- Thermal exchanges due to conduction, convection and radiation.
- Fluid dynamics related to ventilation.
- Properties of moist air, thermal comfort and thermo-hygrometry.
- Climatic parameters such as the geometry and energy aspects of the sun, wind, ambient temperature and humidity, condensation at the dew point.
- Characteristics of the materials of construction and their response to the evolution of parameters inside and outside the built space.

There are two other parameters which need to be understood and taken into consideration while analyzing the dynamic evolution of the heat transfers across the built envelope as a function of the variations in climatic parameters. One concerns the capacity of the construction material to transmit a temperature variation or their diffusivity and the other is the thermal capacity of the material.

Thermal comfort

The comfort depends not only on physical parameters such as temperature and humidity but also on physiological and psychological factors. Therefore, instead of the comfort corresponding to a single temperature and partial pressure of water vapour, a 'comfort zone' is generally defined.

The human body is a generator of heat due to metabolism at three levels:

- Metabolism that is needed for survival which is approximately 75W
- Metabolism at rest, corresponding to the minimum heat produced when the body is at rest, which is around 105W
- Metabolism due to the physical activity undertaken

The human body exchanges heat with the surrounding by conduction (negligible), convection, radiation and evaporation. The last is a sort of efficient convection because the latent heat of evaporation is fairly high Moreover, unlike the other heat transfer modes, this transfer is always in one direction only, from the body to the surrounding. Evaporation is a function of the air velocity and the partial pressure of water vapour in the air.

To achieve comfort, the metabolism should balance the thermal losses. Practically, comfort depends on parameters such as:

- Metabolism corresponding to the human activity
- Temperature of the bodies which surround the human body and heat exchange by radiation.
- Temperature of the ambient air.
- Partial pressure of the water vapour in the air.
- Air velocity
- Thermal resistance of the dresses which reduce the thermal exchanges of the human body.
- Permeability of the dress which allows evaporation from the skin.

The effect of radiation can be quite important. In a warm climate, a point closer to a hot part of the building envelope will have a higher radiant temperature than a point away from it.

- For all practical purposes, comfort can then be determined by three parameters.
- Resulting (radiant) temperature.
- Partial pressure of water vapour in the air.
- Air velocity.

Behaviour of the building envelope

After getting some insight into the various parameters which intervene in a building, one can proceed to see how the comfort level inside a built space can be achieved by playing around with them.

In order to assess the behaviour of the building envelope, one should note that the building is never in steady state because:

- The ambient temperature varies over the day.
- Solar radiation is periodical and may be absorbed by certain opaque parts of the envelope and penetrates inside through some openings.
- The internal heat gains due to metabolism, appliances, cooking, etc. also vary with time.
- The air velocity inside the building changes with time.

This is a fairly complex dynamic problem and can be easily simulated using computer tools once the physical phenomena occurring there are taken into account.

There are certain thermal exchanges across a building envelope:

- Heat exchange due to the difference between inside and outside temperatures
- Incident solar radiation which varies periodically
- Part of the solar radiation absorbed by the opaque wall and part of the radiation transmitted through the glazed openings
- Heat gains due to internal activities.
- Difference of temperature between the air coming in and that leaving the building due to ventilation or air renewal.

These interactions lead to a periodic evolution of the temperature inside the building and the building envelope itself absorbs and releases certain heat flux periodically As the building envelope undergoes a cyclic change of temperature, its inside temperature can be considered to be oscillating around an average value. One can then·

- Calculate this average temperature with sufficient accuracy as a function of the average values of the above-mentioned parameters which influence the inside temperature
- Conduct qualitative analysis to identify the measures to be taken to reduce the oscillations.
- Take action so that the average maximum and minimum inside temperatures lie within the comfort zone naturally or by means of minimum energy expenditure.

In general, without considering the use of artificial heating or cooling, it is necessary to raise the average inside temperature of a building in cold regions or periods and reduce the average inside temperature in warm zones or periods.

Decreasing the average inside temperature

In order to decrease the average inside temperature of a building in warm region or season, the designer has the option of acting on:

- Average internal gain in a manner so that it remains the minimum possible.
- Average solar gains through the glazing which should be the minimum.
- Overall conductivity which should be increased.
- Average a ventilation rate which should also be increased during favourable periods.

As seen earlier, here too, some parameters are dependent. For instance, increasing the conductivity by providing more opening area and increasing the conductivities of the opaque surfaces also result in enhancing the solar gain through some glazing and some surfaces of the envelope exposed to the sun

The following are the systematic measures that have been undertaken to reduce the average inside temperature of the buildings

1 Reduction of the internal heat gains Energy efficient artificial lighting design with daylight integration has been adopted to reduce internal gains

2 Reduction of the solar radiation absorbed by the glazing: Knowledge of the solar path in warm period or region confirms that incident solar energy is:

  - Poor on the south and/or north vertical planes.
  - Quite important on the east and west facing vertical planes
  - Considerable on the planes which are closer to the horizontal.

Therefore, to reduce the solar input through the glazed areas to a minimum value, the following measures have been adopted·

  - Provided openings of reasonable dimensions and heights for natural lighting. Mostly on the north and south facades and as little as possible on the east and west facades. Whenever possible. east has been preferred to west, which accumulates a lot of heat due to the more elevated temperature in the afternoon. Such an arrangement which favours north-south exposure not only reduces the possibility of direct solar gains in a very simple manner such as installation of solar protection devices and even complete closing of the openings in areas which are not used during the day.
  - Horizontal overhangs (or extension of the roofs) with slight extension from the plane of the glazed area, are often very effective in protecting the building components from solar exposure. These have been adequately sized to give complete shading to the windows for most part of the year
  - Solar radiation being closer to the perpendicular with the east-west directions. horizontal solar protection should be provided with considerable extension to be effective. As this solution tends to reduce natural lighting, vertical fins have been provided with a proper angle to benefit from the day lighting whenever it is possible. One should not forget the use of vegetation which is always an inexpensive alternative, with the additional benefit on the microclimate at the

site. The architect has catered to this requirement quite adeptly.

3. Reduction of the solar radiation absorbed by the walls and roof, this has been achieved by taking the following measures:
   - Designing an envelope which presents the minimum possible exposed surface area close to the horizontal and even oriented toward east or west.
   - Treating the surface areas of the envelope exposed to the sun with selective materials having low absorptivity and high reflectivity. The top surface of the roof is being treated with glazed tiles for reflecting the incident heat on the roof
   - Constructing cavity walls of the envelope.
   - Protecting the envelope, particularly the portion which receives a lot of solar energy, by shades which block the solar radiation and are themselves cooled by natural ventilation.
4. It is better management of the ventilation rate which gives the designer the power to eliminate the solar and internal gains Higher the ventilation rate, lower will be the difference between the inside and outside temperatures. Except in the case of very high conductivity of the envelope (without any insulation), the average inside temperature decreases rapidly first with the increase of ventilation rates The average temperature is not influenced by the oscillations of temperatures when the ventilation rate is constant.

Though an increase in the ventilation rate reduces the temperature difference, in climates where the outside temperature varies considerably between day and night, varying the ventilation rate brings in certain advantages. For instance, increasing the ventilation rate during day when the outside may be hotter than inside does not bring any improvement in comfort The air renewal rate may, in that case, be just the amount needed to satisfy the hygienic requirements. The ventilation rate can be increased considerably at night when the outside may be much cooler than the inside.

The required ventilation may be obtained naturally by adequate designing of the openings However, to take the best advantage of the day and night temperature differences when they are significant one may use simple fans for enhancing the air renewal rate

Design of a building requiring air-conditioning

In some situations, as in the laboratory block of the building due to functional requirements air-conditioning has to be provided.

In a general manner, the moment a constant temperature is imposed by air conditioning, there is no need for inertia in the building. Properly sealed and adequately sized windows with optimum overhang sizes have been provided in the air-conditioned spaces to reduce the air-conditioning load of the building.

Conclusion

A few fundamental notions concerning the interaction of the building with its environment and how these have been tackled in present design are elaborated in the chapter, in order to come up with a fairly suitable building which will not only overcome the local climatic constraints but also makes use of the prevailing conditions to render the living space thermally comfortable while consuming practically little additional energy

CHAPTER 2

Lighting design and thermal performance evaluation methods

Day lighting Design

The main objectives of day lighting design are:

1. To find out the adequate window area to provide the recommended daylight factor either at the center or at the rear, on the working plane and
2. To calculate the lighting levels at different grid points on horizontal and/or vertical planes due to daylight provided through that window area

Many day lighting design and analysis methods are existing to accomplish the above mentioned tasks but in India daylight factor method is recommended for day lighting design. Again a variety of procedures are used for the determination of daylight factor components These include simple formulae, pre calculated look up table, protectors, sky vault projection diagrams, and nomograms.

For day lighting design in India, Central Building research Institute (CBRI), Roorkee has provided simple graphs, lux grid, protractors and nomograms which are specially developed for Indian design sky. Based on CBRI design principles and methods two computer programs have been developed by TERI to correlate amongst window sizes, location area, reflection coefficient of walls and indoor illumination due to daylight A brief description of these computer programs are given below

WDESIGN Program

As mentioned above, the program is based on the CBRI design method and for a recommended daylight factor either at the center point or the rear point, calculates the window area (both gross and effective) of a centrally located or corner located window placed either on the shorter wall or longer wall of the room. The input file of this program is given in annexure 1.

Daylight Program

This program has been developed based on the equations formulated by Saxena et al of CBRI, Roorkee. The program does the point by point calculation of daylight components and levels at predefined grid points on a horizontal and/or vertical work planes due to the provided window(s). The program also studies the effect of following parameters on the indoor daylight levels.

- area of opening (window /ventilator)
- room height
- sill height as compared to working plane height

- reflection coefficients of wall
- area of room
- opening width to height ratio
- location of windows.

An output file of program is given in annexure no.1.

Design of Shading Devices

External shading devices are designed by using tables prepared by CBRI. These tables have been developed by the application of the solar chart and solar angle protractor for designing shading devices for openings in the eight cardinal and semi-cardinal orientation orientations The whole country has been divided into two regions, namely, (a) northern, that is, north of latitude 20° N and (b) southern, that is, south of latitude 20° North. The same shading device is generally adequate for a whole region and the difference from one region to other also is small. The tables recommend a louver system for a specific performance and for a particular direction and give the spacing distances between vertical or horizontal members of louver systems in terms of the outward projection of the perpendicular to the wall

Artificial Lighting Design

The main aim of an artificial lighting design is to provide recommended illuminance for carrying out a specific task in different areas of the buildings The important parameters considered are: Illumination to be provided. lighting system selection. lighting equipment e g. lamps, luminaires and ballasts and controls. Both manual and software packages are available for design and analysis Accuracy and time constraints always advocate use of computer programs for lighting design.

Spec Writer Program

For artificial lighting design SpecWriter software package is used which is not just one lighting program but a very powerful lighting analysis, calculation and photometric tools These tools work together as one total lighting mechanism to enhance lighting design analysis productivity SpecWriter output includes accurate indoor and outdoor lighting estimates, basic lighting calculations, and sophisticated point-by-point analysis This program has been developed by Hubbell Incorporated, USA.

Thermal analysis

The impact of day lighting and efficient artificial lighting on the thermal behaviour of the building is generally studied by the thermal analysis of the building. The thermal analysis is carried out by simulation using a software package called SUNCODE.

Suncode Program

determines the maximum indoor temperature for non-conditioned space and cooling load for air-conditioned spaces by doing hour by hour calculations. The program conceptualizes the building as consisting of convenient zones and translates the thermal model of the building into a mathematical form The mathematical equations are then solved repeatedly at small time interval (less than a hour) for a user specified period (either one representative summer day or one winter day or both. The mathematical representation of the building is a thermal network with non-linear temperature dependant controls The mathematical solution techniques uses a combination of forward finite difference, Jacobean iteration and constrained optimization.

CHAPTER 3

Lighting and thermal analysis and recommendations

The lighting analysis can be classified under two i.e daylight analysis and artificial lighting analysis

Daylight Analysis

Required Fenestration Area for Recommended Daylight Factor

For both south facing and north facing laboratory blocks the required fenestration area for recommended daylight Factor has been calculated using WDESIGN computer program. Following assumptions have been made for analysis

• window position	centrally located
• window location	on longer wall
• design criteria	daylight factor at the centre
• recommended daylight factor :	3 5%
• effective area	fully glazed
• type of frame	metallic
• external obstruction	nil

Point - by - Point Daylight Level Calculations

Daylight program has been used to calculate the daylight levels at different grid points. For this calculations following assumptions have been made

• room height	3.6m
• work plane height	0 90m
• sill height	0.90m
• effective opening area of window	84% of the gross window area
• maintenance factor for glass	0 80
• Design sky illuminance	8000 lux
• average reflection coefficient of walls :	0 50
• average reflection coefficient of roof	0 70
• average reflection coefficient of floor :	0 10

Shading devices (louvers) design

Shading devices for laboratory and office blocks have been designed by using tables developed by CBRI and given in Handbook on functional requirements of buildings (other than industrial buildings), a BIS publication. Following assumptions have been made for design;

- Table giving spacing distances between vertical or horizontal members of louver systems (Northern Region) have been used for design.
- For north facing windows:
    - Type of louver : Vertical
    - Louver's performance : Cuts-off after 7 am during June and completely in other months
    - Angle of inclination : 0°
- For south facing windows
    - Type of louver Horizontal
    - Louver's performance . completely cuts-off summer sun and allows winter sun indoors
    - Angle of inclination . 0°
- For windows facing east/west
    - Type of louver egg- crate
    - Louver's performance : completely cuts-off only summer sun but allows winter sun to come partially
    - Angle of inclination for vertical member 30° away from normal towards south
    - Angle of inclination for horizontal member · 0°

Artificial Lighting Design

Lighting schemes for different areas have been developed by using SpecWriter program. The main assumptions made are given below

- Reflectance
    - West Wall 0 50
    - North wall : 0 50
    - East wall · 0.50
    - South wall . 0 50
    - Floor : 0.10
    - Ceiling : 0.70

- Average illuminance : 250 lux
- Light loss factor : 0.85
- Lumen out put of the lamp : 3250 lumens

• Wattage of lamp	:	36W
• Type of luminaire	:	Bat-wing mirror optics type

Thermal Analysis

The thermal analysis of PCB building has been done by simulation. The computer program used for simulation of a building conceptualizes the building as consisting of a number of convenient zones, translates the thermal model of the building into a mathematical form. The mathematical equations are then solved repeatedly at small time interval (less than one hour) for a user specified period (for one representative summer day in this case). The mathematical representation of the building is a thermal network with non-linear temperature dependant controls.The mathematical solution technique uses a combination of forward finite difference, Jacobean iteration and constrained optimization.

The basic purposes for which simulation has been done are as follows

- To determine the maximum indoor temperature for office space with various combination of window & shading device
- To determine the cooling load for air-conditioned laboratory spaces.
- To study the effect of various window types and shading devices on cooling load of the laboratory spaces

Inputs for simulation

Meteorological data for Calcutta has been used for simulation.

Building input

·The Pollution Control Board building is a five storied non air-conditioned building with a few areas such as laboratories, computer room, library and auditorium as air-conditioned areas.

Simulation was done separately for office and laboratory areas. A single floor of the office building has been simulated as a single zone space The window areas on each surface (North, South, East & West) have been accounted for separately. Each window has been defined in terms of size and location on the surface. Shading devices of window was also defined. This was necessary so as to study the thermal effect of the shading devices on the respective areas. The frame areas for window were considered separately and treated as a wall. For optimizing the window sizes for daylighting, six cases were considered with various combinations of window and shading devices and simulation was run for each case. The various cases considered were as follows:-

Case (1) Proposed window and proposed shading

This is the base case for analysis with window and shading devices as designed by the architect.

Case (2) Proposed window & modified shading

In this case, the window sizes are as designed by the architect but the shading devices have been modified as shown in table 3 (office),table 1 (typical north facing laboratory), table 2 (typical south facing laboratory).

Case (3) Modified window & proposed shading

Modified window is the one with top light removed and the rest of the window is the same as in the proposed case, the shading remaining as proposed by the architect.

Case (4) Modified window & modified shading

In this case the window is the one with top light removed and the shading device is as given in table 3 (office),table 1 (typical north facing laboratory), table 2 (typical south facing laboratory).

Case (5) Recommended window & proposed shading

This window has been designed to provide daylight as recommended by the Central Building Research Institute (CBRI) and the shading remains same as proposed by the architect.

Case (6) Recommended window & recommended shading

This window has been designed to provide daylight as recommended by CBRI and the shading device has been designed as given in table 3 (office),table 1 (typical north facing laboratory), table 2 (typical south facing laboratory)

A sample input file for simulation of office and laboratory spaces has been enclosed. It may be seen that acceptable value of several parameters like air change rate, heat transfer co-efficient etc., have been assumed

Description of basic input data for the simulation

Latitude	22.53°
Longitude.	88.3°
Elevation	6m above sea level

Basic building parameters

Height·	3 6m
Area·	As per plan

Construction details

Walls.	250mm thick brick wall with 19mm thick internal sand cement plaster and 18mm thick external sand cement plaster.
Ceiling:	100mm thick RCC roof with 6mm thick internal plaster and stone flooring

Thermal properties of Building Materials

Table 3.1.

Material	*Conductivity W/mk*	*Density kg/m^3*	*Specific heat*
Plaster	0 72	1762.0	0.84
RCC	1.58	2288	0.88
Brick	0.811	1820 0	0.88
Aluminium	160	2800 00	0.89

Description of various cases considered and the associated lighting and thermal analysis

Laboratories

Case I- Proposed window and proposed shading

(a) Window & Shading

In the north facing laboratory daylighting is provided mainly through vertical windows of 4 2 × 1 2m size and top lights of 4 2 × 0.6m (Figure 3 1) The total glazed area is approximately 15% of the floor area. The windows are centrally located and placed on the longer wall of the room. The windows are shaded with the help of continuous horizontal louvers of 0.5m projection. Horizontal louvers not only shade the window but also reflect the sunlight or externally reflected light through the top light to lit the exterior zone and hence acts as a light shelf Partial shading of top light is provided with the help of chajja which is again a horizontal projection of 0 5m and about 0 60m above the top light.The window arrangement of the south facing laboratory is similar to that of the north facing laboratory, the glazed area being 23 6% of the floor area (Figure 3.2) The windows have selected reflective coating on its glass.

(b) Daylight levels

Daylight levels have been calculated using the daylight software at the grid points on a horizontal plane at work plane height of 0.9m The average daylighting level near the window is approximately 770 lux, at the centre is 480 lux approximately and at the rear is 330 lux (Figure 3 1) In the south facing laboratory the levels near the window is 770 lux, 610 lux at the centre and 490 lux at the rear (Figure 3 2) More than 80% of the room have been over illuminated. The over illumination not only causes visual discomfort but also affects the quality of the lighting standards. It also adds to solar load which leads to either thermal discomfort or more energy consumption.

(c) Zone temp/cooling load

Software package SUNCODE has been used to analyze the impact of daylighting on the thermal behaviour of the room. One day profile of cooling load variation of a typical summer day has been plotted (Figure 3.3). The maximum load of a north facing laboratory of the intermediate floor is approximately 8.5 TR and it occur at around 3 PM. For a south facing laboratory, the peak load is 4.2 TR which occurs at 3 PM (Figure 3.4) The load of the corresponding top floor laboratories are about 30% higher Use of underdeck insulation can reduce this topfloor load by approximately 8%.

Case II - Proposed window modified shading

(a) Windows & Shading

In this iteration, the window size is as in Case I i.e., 4.2 × 1.2m vertical windows and 4 2 × 0.6m top lights The glazed area and window location are the same as in earlier case. The shading has been devised to cut off direct sun during most part of the day The shading device for window and top light of north facing laboratory (Figure 3.5) has been modified to 0 56m vertical, with one extra vertical member at the centre The projection for window of south facing laboratory has worked out to 0.7m horizontal (Figure 3 6) and that for top light has worked out to 0.35m

(b) Daylight levels

Daylight levels have been calculated at grid point intervals of in and out at a work plane height of 0.9m. For the north facing laboratory the levels at 1m from the window is an average value of 610 lux, at the centre is approximately 360 lux, and at the end in 250 lux (Figure 3 5) For the south facing laboratory the levels at 1m from the window is an average value of 790 lux, at the centre is approximately 580 lux, and at the end in 440 lux (Figure 3 6) The levels which are high in the proposed case have been reduced substantially with the modified shading devices. Modified shading has also reduced the direct solar load on the windows thus reducing the cooling load of the space which in turn cuts down the energy consumption

(c) Cooling load

Suncode simulation has been used to analyse the impact of daylighting on the thermal behaviour of the room Cooling load profile for the North facing laboratory of a typical summer day (May 16) showed that the peak load is between 15 00 hrs to 16.00 hrs and is about 7 72 TR (Figure 3 7). The loads have been scheduled between 9 00 and 18.00 hrs. The south facing laboratory had a maximum loading load of 4 17 TR between 15 00 hrs and 16.00 hrs (Figure 3.8)

Case III - Modified window and proposed shading

(a) Windows & Shading

The top light was excluded from the proposed window to give the modified window. The shading devices was as in the Case 1 (i.e. as proposed by the architect). Daylighting is provided through vertical windows Top light being removed, there is no scope for reflected light from the light shelves. The glazed area of North facing laboratory is 12.7 m^2 which is 10% of the floor area (Figure 3.9) The glazed area of the south facing laboratory is 8.5 m^2 which is about 15.8% of the floor area (Figure 3.10).

(b) Daylight levels

Daylighting levels have been calculated using the daylighting software at grid intervals 1m × 1m and at a work plane height of 0 9m. The daylighting levels near the window is 720 lux, 260 lux at centre and 160 lux at the rear for the north facing laboratory (Figure 3 9) For the south facing laboratory, daylight levels near the window was 710 lux, at the centre was 430 lux and at the rear was 290 lux (Figure 3.10).

(c) Cooling Load

The peak cooling load for the north facing laboratory of an intermediate floor is 8 05TR on a typical summer day (Figure 3 11). The corresponding south facing laboratory attains a peak of 4 01TR at the same time (Figure 3 12) Use of low e glass cuts down the cooling load by 10%.

Case IV - Modified window and modified shading

(a) Window and shading

In this case the window and the glazed area is as in Case III with shading as in Case II. (Figure 3 13) and (Figure 3 14)

(b) Daylight levels

In the north facing laboratory, the levels adjacent to window is 570 lux, at the centre is 230 lux and at the rear is 150 lux at a work plane height of 0 8m (Figure 3 13). In the south facing laboratory the levels near the window is 680 lux, at the center is 420 lux and at the rear is 290 lux (Figure 3 14).

(c) Cooling load

Suncode simulation was used to determine the change in cooling load by changing the window and shading device simultaneously. The cooling load profile for a typical summer day showed a peak load of 7.5 TR for a north facing laboratory (Figure 3 15) of an intermediate floor (the load of top floor rooms are about 30% higher than that of intermediate floor) The peak is

4.17 TR for a south facing laboratory (Figure 3.16). The peak load occurs at a time of 3 pm.

Case V - Recommended window and proposed shading

(a) Windows & Shading

The recommended window size has been worked out using a software which is based on CBRI standard for window design for recommended daylight factor on work plane. The size determined is adequate for recommended DF of 3.5 at work plane The window area for north facing laboratory worked out to 3 × 1 2m and the top light area worked out to 3 × 0.6m each (Figure 3.17). For south facing laboratory, the top light is not required and the window sizes worked out to 3 x 1.2m each (Figure 3.18) The glazed area in the north facing laboratory is 13 6m^2 which is about 10.7% of floor area In the south facing laboratory the glazed area is 6m^2 which is about 11.3% of the floor area The shading is as provided by the architect.

(b) Daylight level

Daylight levels calculated at 1m x 1m grid points gave an average of 560 lux near the window, 350 lux at the centre and 240 lux at the rear for a north facing laboratory (Figure 3 17). For the south facing laboratory, the daylight levels worked out to 510 lux near the window, 310 lux at the centre and 215 lux at the rear (Figure 3 18)

(c) Cooling load

Cooling load profile has been plotted for a typical summer day for north and south facing laboratories. The maximum cooling load has worked out to 8 00 TR at about 3 pm for a north facing laboratory (Figure 3 19) The value for the south facing laboratory is 3.91 TR (Figure 3.20) The loads mentioned above are for intermediate floor For the corresponding top floor rooms, the loads are about 30% higher. Simulation using low e glass for windows showed a reduction of 10% in cooling load over the used glass type.

Case VI - Recommended window recommended shading

(a) Window and shading

The window size is as in previous case (Case V).The recommended shading is 0 80m wide vertical fins for vertical windows and for top lights for the north facing laboratory (Figure 3 21) For the south facing laboratory, the recommended shading is 0.70m horizontal projection for the low level window (Figure 3 22) The shading device has been designed so that it cuts off sun from 7 a m onwards during June and completely in other months for North

Facing laboratory. The shading for South facing laboratory would completely cut off summer sun and would winter sun indoors.

(b) Daylight levels

The daylight levels worked out to 450 lux near the window, 270 lux at the centre and 190 lux at the rear for a north facing laboratory (Figure 3.2) For the south facing laboratory the levels worked out to 490 lux near the window, 305 lux at the centre and 130 lux at the near (Figure 3.22) .

(c) Cooling load

The cooling load profile for a typical summer day, showed a peak of 8.0 TR for a north facing laboratory (Figure 3 23) and 4 0 TR for a south facing laboratory (Figure 3.24). Use of low e glass can cut down the load further by 10%

Office block

Case 1 Proposed window proposed shading

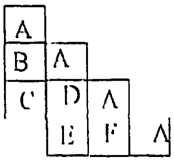
(a) Window and shading

Day lighting is provided through vertical windows and adjoining top lights (Figure 3 25) . The windows are mostly sized at 4 725 × 1 2m partly fixed and partly openable side hung openable shutter with top light of 4.725 × 0.6m which are fully fixed Al-windows. Shading for vertical windows is provided by chajja of 0 5m The top light is also shaded by projection with effective length of 0 5m The glazed area on the east and west sides are about 8.8% of the floor area. Glazed area on the North is 4 2% of the floor area and on the south face is 8.8% of the floor area

(b) Daylight levels

The daylight levels were calculated at grid spacing of 1 m and at a working plane of 0.8m. The level near windows on all sides was 1540 lux The average levels at centre of blocks (as given in the key plan) (Figure 3.25) are as follows·

Block A - 1190 lux
Block B - 740 lux
Block C - 800 lux
Block D - 960 lux
Block E - 850 lux
Block F - 780 lux



The entire office space is over illuminated which causes visual discomfort. It adds to the solar load which leads to elevated zone temperatures during summers.

(c) Zone temperatures

A software package SUNCODE PC has been used to analyze the impact of day lighting on the thermal behaviour of the room. The office area being non conditioned, the zone temperature profile for the office space of an intermediate floor and top floor is plotted (Figure 3.26). For an intermediate floor, the maximum zone temperature is a maximum of 36° C at about 1700 hrs when the ambient reaches a maximum of 35 8°C at about 1500 hrs The corresponding top floor office space reaches a maximum of 40 7°C.

Case II Proposed window modified shading

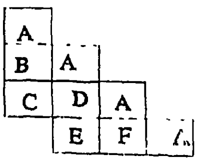
(a) Window and shading

Day lighting is provided through vertical windows and adjoining top lights (Figure 3 27). The windows are mostly sized at 4 725 × 1.2m partly fixed and partly openable side hung openable shutter with top light of 4 725 × 0.6m which are fully fixed Al-windows Shading for north facing windows and top light is by 0.64m wide vertical fins with one extra member at the centre of the window, for the south facing window it is 0 7m horizontal and for south facing top light it is 0.35m horizontal to cut off summer sun The modified shading for the east/west facing windows and top lights is a combination of vertical and horizontal members with 0 72m horizontal projection and 18 numbers vertical members 0 10m thick inclined by 30° to the south The glazed area on the east and west sides are about 8 8% of the floor area Glazed area on the North is 4 2% of the floor area and on the south face is 8 8% of the floor area.

(b) Daylight levels

The daylight levels were calculated at grid spacing of 1 m and at a working plane of 0 8m The level near windows on all sides was 1160 lux. The average levels at centre of blocks (as given in the key plan) are as follows (Figure 3.27):

Block A - 840 lux
Block B - 760 lux
Block C - 480 lux
Block D - 750 lux
Block E - 490 lux
Block F - 610 lux



The entire office space is over illuminated which causes visual discomfort It adds to the solar load which leads to elevated zone temperatures during summers

(c) Zone temperatures

A software package SUNCODE PC has been used to analyze the impact of day lighting on the thermal behaviour of the room. The office area being non conditioned, the zone temperature profile for the office space of an intermediate floor and top floor is plotted (Figure 3.28). For an intermediate floor, the maximum zone temperature is a maximum of 34 9°C at about 1700 hrs when the ambient reaches a maximum of 35 8°C at about 1500 hrs The corresponding top floor office space reaches a maximum of 39 6°C

Case III Modified window proposed shading

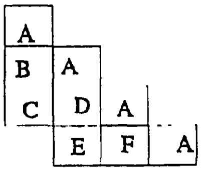
(a) Window and shading

In this case the windows remain as in earlier cases and the top lights have been excluded (Figure 3 29). The windows are mostly sized at 4 725 × 1 2m partly fixed and partly openable side hung openable shutter. Shading for all vertical windows is provided by chajja of 0.5m. The glazed area on the east and west sides of each floor are $19m^2$ which is 5 9% of the floor area. Glazed area on the North is $9m^2$ which is 2 8% of the floor area and on the south face is $19m^2$ which is 5 9% of the floor area

(b) Daylight levels

The daylight levels were calculated at grid spacing of 1m and at a working plane of 0 8m The level near windows on all sides was 1200 lux The average levels at centre of blocks (as given in the key plan) are as follows (Figure 3.29)

Block A - 640 lux
Block B -400 lux
Block C - 550 lux
Block D - 590 lux
Block E - 570 lux
Block F - 470 lux



The office space is still over illuminated. It adds to the solar load which leads to elevated zone temperatures during summers.

(c) Zone temperatures

A software package SUNCODE PC has been used to analyze the impact of day lighting on the thermal behaviour of the room. The office area being non conditioned, the zone temperature profile for the office space of an intermediate floor and top floor is plotted (Figure 3 30). For an intermediate floor, the maximum zone temperature is a maximum of 35 6°C at about 1700 hrs when the ambient reaches a maximum of 35.8°C at about 1500 hrs The corresponding top floor office space reaches a maximum of 40.3°C

Case IV Modified window modified shading

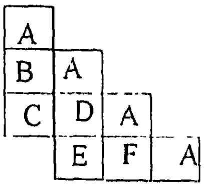
(a) Window and shading

In this case the windows remain as in earlier cases and the top lights have been excluded (Figure 3 31) The windows are mostly sized at 4.725 × 1 2m partly fixed and partly openable side hung openable shutter. Shading for north facing windows is by 0 64m wide vertical fins with one extra member at the centre of the window, for the south facing window it is 0 7m horizontal The modified shading for the east/west facing windows is a combination of vertical and horizontal members with 0.72m horizontal projection and 18 numbers vertical members 0.10m thick inclined by 30° to the south. The glazed area on the east and west sides are about 5 9% of the floor area. Glazed area on the North is 2.8% of the floor area and on the south face is 5.9% of the floor area.

(b). Daylight levels

The daylight levels were calculated at grid spacing of 1m and at a working plane of 0 8m. The level near windows on all sides was 980 lux. The average levels at centre of blocks (as given in the key plan) are as follows (Figure 3.31) ·

Block A - 570 lux
Block B - 360 lux
Block C - 415 lux
Block D - 510 lux
Block E - 430 lux
Block F - 400 lux



The office space is illuminated within acceptable limits with certain pockets with over illumination.

(c) Zone temperatures

A software package SUNCODE PC has been used to analyze the impact of day lighting on the thermal behaviour of the room. The office area being non conditioned, the zone temperature profile for the office space of an intermediate floor and top floor is plotted (Figure 3.32) For an intermediate floor, the maximum zone temperature is a maximum of 34 8°C at about 1700 hrs when the ambient reaches a maximum of 35 8°C at about 1500 hrs. The corresponding top floor office space reaches a maximum of 39 5°C

Case V Recommended window proposed shading

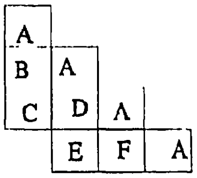
(a) Windows and shading

The window sizes required to provide recommended day lighting for the interior office spaces have been calculated to be 2 × 1.2m each on all sides (Figure 3.33). The top lights are also not required. In this case the shading has been retained as designed by the architect, i.e., 0.5m from the outer face of the wall. The glazed area on the north face is 4m^2 which is 1.2% of the floor area, that on the east and south sides are 8m^2 each which is 2.5% of the floor area in each case.

(b) Daylight levels

The daylight levels were calculated at grid spacing of 1m and at a working plane of 0.8m. The level near windows on all sides was 510 lux. The average levels at centre of blocks (as given in the key plan) are as follows (Figure 3.33):

Block A - 330 lux
Block B - 190 lux
Block C - 330 lux
Block D - 250 lux
Block E - 300 lux
Block F - 190 lux



The office space is illuminated within acceptable limits and is quite uniformly lit.

(c) Zone temperatures

A software package SUNCODE PC has been used to analyze the impact of day lighting on the thermal behaviour of the room. The office area being non conditioned, the zone temperature profile for the office space of an intermediate floor and top floor is plotted (Figure 3.34). For an intermediate floor, the maximum zone temperature is a maximum of 35.0° C at about 1700 hrs when the ambient reaches a maximum of 35.8°C at about 1500 hrs. The corresponding top floor office space reaches a maximum of 39.7°C

Case VI Recommended window recommended shading

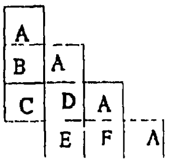
(a) Windows and shading

The window sizes required to provide recommended day lighting for the interior office spaces have been calculated to be 2 × 1.2m each on all sides. The top lights are also not required. The glazed area on the north face is 4m^2 which is 1.2% of the floor area, that on the east and south sides are 8m^2 each which is 2.5% of the floor area in each case. The recommended shading on the north side is vertical shading of width 0.54m, on the south side is 0.7m horizontal projection at the top and for the east side is 0.7m horizontal at the top in addition to seven vertical members 0.10m thick inclined by 30° towards south (Figure 3.35)

(b) Daylight levels

The daylight levels were calculated at grid spacing of 1m and at a working plane of 0.8m The level near windows on all sides was 370 lux. The average levels at centre of blocks (as given in the key plan) are as follows (Figure 3.35):

Block A - 290 lux
Block B - 190 lux
Block C - 290 lux
Block D - 250 lux
Block E - 290 lux
Block F - 190 lux



The entire office space becomes underlit by day lighting only and requires supplementary lighting in certain pockets, i.e., in B, D and E.

(c) Zone temperatures

A software package SUNCODE PC has been used to analyze the impact of day lighting on the thermal behaviour of the room The office area being non conditioned, the zone temperature profile for the office space of an intermediate floor and top floor is plotted (Figure 3 36) For an intermediate floor, the maximum zone temperature is a maximum of 34 7°C at about 1700 hrs when the ambient reaches a maximum of 35 8°C at about 1500 hrs The corresponding top floor office space reaches a maximum of 39 4°C

Table 3.2. Window and shading device design for North facing PCB Lab

Modified shading	*Orientation*	*Window/toplight size*	*Type*	*Performance*	*Projection*
	North	4.2 x 1.2m	Vertical	Cuts-off after 7 am during June and completely in other months	0.56m with one extra vertical member at the centre or 1.12m
		4.2 x 0.6m			
Recommend shading	North	3 x 1.2m	Vertical	-do-	0.80m
		3 x 0.6m	Vertical	-do-	0.80 m

Table 3.3. Shading device design for South facing PCB Lab

Modified shading	*Orientation*	*Window/Toplight size*	*Type*	*Performance*	*Projection*
Case ii and Case iv	South	4.2 x 1.2m	Horizontal	Completely cuts of summer sun & allows winter sun indoors	0 70m
		4.2 x 0 6m	Horizontal	-do-	0.35m
Recommended shading Case vi	South	3 x 1 2m	Horizontal	-do-	0.70m

Table 3.4. Shading device design for PCB Office space

Modified	*Orientation*	*Window/Toplight size*	*Type*	*Performance*	*Projection*
shading (Case ii and Case iv)	North	4 72 x 1 2m	Vertical	same as lab	0.64m with an extra vertical member at centre of the window or 1 28 m
		4 72 x 0 6m	Vertical	same as lab	-do-
	South	4 72 x 1 2m	Horizontal	same as lab	0.70m
		4 72 x 0.6m	Horizontal	same as lab	0.35m
	East/West	4 72 x 1.2m	Combination of vertical and horizontal	completely cuts - off only summer sun but allows winter sun to come partially	
			Horizontal		0.72m one at top and one at bottom.
			Vertical		18 vertical members 0.10m thick inclined by 30° towards south
		4.72 x 0.6m	Horizontal	–do-	0.72 only at top
			Vertical		same as window above
Recommended shading (Case vi)	North	2 x 1.2m	Vertical	same as lab	0 54
	South	2 x 1.2m	Horizontal	same as lab	0.70m at the top
	East/West	2 x 1 2m	Horizontal	same as modified shading	0.7 m at the top

	Vertical	-do-	7 members 0.10m thick inclined by 30 towards south

Final design for the laboratory block and the associated lighting and thermal analysis

North facing laboratory

(a) Windows and shading

Based on recommendations of TERI and their initial design, the architect came up with a final design in which a few of the original features were retained along with incorporation of the recommendations by TERI. In the north facing laboratory the windows were resized to 3 × 1.2m and the top lights were reduced to 3 × 0 5m The net glazed area in the north facing laboratory is $12.9m^2$ which is 10.1% of the floor area The shading has been kept at 0 5m from the building facade with the window glazing recessed at 0.15m from the facade (Figure 3 37). So the effective shading length is 0.65m.The effective shading length for the top lights is 1 05m. Vertical fins have been added as recommended

(b) Daylight levels

The final design has a predicted lux level of 560 lux near the window, 340 lux at the centre and 220 lux at the rear with a design sky illuminance of 8000 lux (Figure 3 37)

(c) Cooling load

In a north facing laboratory of an intermediate floor the cooling load is 7 5 TR at 1500 hrs (fig 3 38) on a typical summer day and that of a top floor laboratory is 11 8 TR at 1500 hrs on the same day.

South facing Laboratory

(a) Windows and shading

Likewise in the South facing laboratory, based on recommendations of TERI and their initial design, the architect came up with a final design in which a few of the original features were retained along with incorporation of the recommendations by TERI In the south facing laboratory the windows were resized to 3 × 1.2m and the toplights were reduced to 3 × 0 5m. The net glazed area in the north facing laboratory is 8 $6m^2$ which is 16% of the floor area. The shading has been kept at 0.5m from the building facade with the window glazing recessed at 0.15m from the facade (Figure 3.39). So the effective shading length is 0.65m. The effective shading length for the top lights is 1.05m.

(b) Daylight levels

The predicted daylight levels in the south facing laboratory near the window is 610 lux, at the centre is 460 lux and at the rear is 320 lux with a design sky illuminance of 8000 lux (Figure 3.39)

(c) Cooling load

In a south facing laboratory of an intermediate floor the cooling load is 3 9 TR at 1500 hrs (fig 3.40) on a typical summer day and that of a top floor laboratory is 5 70 TR at 1500 hrs on the same day

Office space

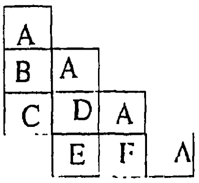
(a) Windows and shading

The windows were reduced from 4 725m × 1.2m to 3m × 1.2m and the toplight sizes were reduced from 4.725 × 0.6m to 3 × 0 5m. The shading device for the north and south faces were retained as designed originally by the architect i.e 0 5m from the outer facade for the window and 0 9m from the outer facade of the wall for the toplight For the east face the windows were each divided into six segments each shaded by a vertical fin inclined at 30° to the south (Figure 3 41) The net glazed area on the east face of each floor is 17.2m^2 which is 5 3% of the floor area, on the north side is 8 6m^2 which is 2 7% of the floor area, and on the south side is 17 2m^2 which is 5 3% of the floor area

(b) Daylighting levels

The daylight levels were calculated at grid spacing of 1m and at a working plane of 0.8m. The predicted daylight levels near to the window is 840 lux The levels at the centre of each block in the adjacent key plan are as follows (Figure 3 41):

Block A- 802 lux
Block B- 338 lux
Block C- 442 lux
Block D- 433 lux
Block E- 442 lux
Block F- 433 lux



Thus we see that a uniform level is being acheived with this option

(c) Zone temperature

Software package SUNCODE PC has been used analyze the impact of day lighting on the thermal behaviour of the room. The office area being non conditioned, the zone temperature profile for the office space of an intermediate floor and top floor is plotted (Figure 3.42). For an intermediate floor, themaximum zone temperature is a maximum of 34.9°C at about 1700 hrs when the ambient reaches a maximum of 35 8°C at about 1500 hrs The corresponding top floor office space reaches a maximum of 40.4°C.

Artificial lighting and control design

North facing laboratory

For the north facing laboratory, the artificial lighting design was based on night time conditions i e, no daylight Then the switching circuits were fianalised based on supplementary lighting requirements during daytime due to daylight integration The artificial lighting was done with average lux level of 250 lux. 10 numbers wide spread mirror optics luminaires each with 2 numbers 36W Trulite (lumen output of 3250 lumens) and HF ballasts at a mounting height of 3.3m was recommended (Figure 3.43). The levels acheived was an average of of 275 lux with a maximum of 358 lux and a minimum of 147 lux at a workplane height of 0 9m The power density achieved was 5.92 W/m^2 In the final design the architect has replaced the fluorescent by 11W PL lamp The space is now lit with 24 × 2 nos 11W PL lamps in Philips type FCS 31/211. The lumen output is 900 lumen/lamp The average lux level achievable at a working plane of 0 9m is 150 lux with maximum of 219 lux and minimum of 77 lux (Figure 3.44) Superimposing the daylight levels and the artificial lighting levels it was found that the lighting in row 2 can be kept switched off during daytime between 1100 hrs and 1500 hrs and hence connected to a timer with a local override. The levels achieved has been shown in Figure 3 45 (for space lit with fluorescent lamps) and Figure 3 46 (for space lit with compact fluorescent lamps)

South facing laboratory

Similarly for the south facing laboratory the artificial lighting was designed for no light condition. The design lux level was taken as 250 lux. 6 numbers of twin tube widespread mirror optics luminaire with 2 nos 36W Trulite and HF ballasts has been recommended at a mounting height of 3 3 m (Figure 3.47). The average lux level achieved is 265 lux with a maximum lux level 445 lux and a minimum of 101 lux. at a workplane height of 0 9m The power density achieved is 8 37W/m^2 In the final design, the architect has replaced the fluorescent lamps by compact fluorescent 11W PL lamps with lumen output of 900 . lumens/lamp Each laboratory space on south side is now lit by 16 nos FCS 31/211 with 2 ×

11W PL lamps. The average lux level achieved at a workplane height of 0.9m is 190 lux with a maximum of 260 lux and a minimum of 111 lux (Figure 3.48) Superimposing the daylight levels and the artificial lighting levels (Figure 3.49) it was found that the lighting in row I have to be kept switched on during daytime and the remaining can be kept off. Levels with similar switching arrangements and using 11W PL lamps as suggested is shown in Figure 3.50. However incase of lower outside illumination levels the lights marked 2 can be switched on. Lights marked 3 are to be switched on at the latest if required.

Office space

For the office space, the artificial lighting was designed for an average lighting level of 250 lux at a workplane height of 0 9m 4 numbers twin tube widespread mirror optics luminaires each with 2 nos 36W Trulite and HF ballasts with a mounting height of 3 3m was recommended for a grid of 6m × 6m size (Figure 3.51) The average lighting level came to 255 lux with a maximum of 340 lux and a minimum of 136 lux. The power density achieved was 8 33 W/m^2 The architect has adopted rail type twin tube fixture instead with bare 2 × 36W Trulite lamps. The layout remains as suggested The average lux level comes to 349 lux with a maximum of 425 lux and a minimum of 174 lux (Figure 3 52) However during daytime we find that with proper daylighting there is very little supplementary lighting (Figure 3.53) required for the office spaces apart from a few dark zones. Figure 3 54 gives the supplementary lighting levels with lamps switched off as in earlier case but using rail type fixture and 36 W Trulite. Thus the switching circuits have been designed such that lamps marked 1 are to be kept on one circuit and the ones marked 2 to be kept on separate circuit The lamps marked 1 are to be kept on during the office hours and the ones marked 2 are to be kept off between 1100 hrs and 1500 hrs. Switching is to be controlled by timers with manual local overrides

Conclusions

The aim of the study was to achieve an optimised window and shading device design in order to attain energy savings By doing this iterative exercise, the savings achieved has been tabulated as given below The detailed analysis of the final design reveals that there is a possibility to save approximately 64 5% energy in lighting consumption, approximately 11 2% in HVAC consumption and a total of approximately 39 8% saving in lighting and HVAC consumption over proposed design without compromising with the levels of recommended visual and thermal comforts

However, the Architect has already employed solar passive techniques with respect to orientation and depth of plan This in itself has led to a saving of about 2.6% over a conventionally designed building.

Hence, combining the techniques of correct orientation, depth of plan, window and shading device control, we may say that the Pollution Control Building at Salt Lake saves 41.5% annually in energy cost.

Table 3.5. Lighting consumption on a typical floor

Area	*Annual Energy Consumption (kWh)*	
	Proposed design with proposed shading	*Final Design (adopted)*
North facing lab	5070	936
South facing lab	2150	624
Office block	12960	5610
Total	20180	7170
Saving	64.5%	

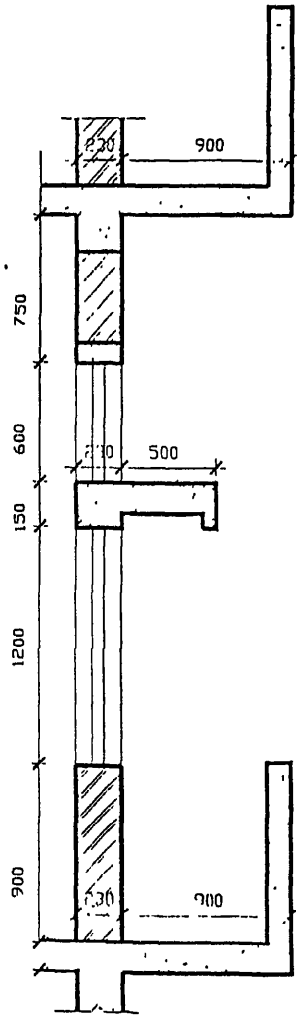
Table 3.6. HVAC consumption on a typical floor

Area	*Annual Energy Consumption (kWh)*	
	Proposed design with proposed shading	*Final Design (adopted)*
North facing lab	11592	10080
South facing lab	5760	5328
Total	17352	15408
Saving	11.2%	

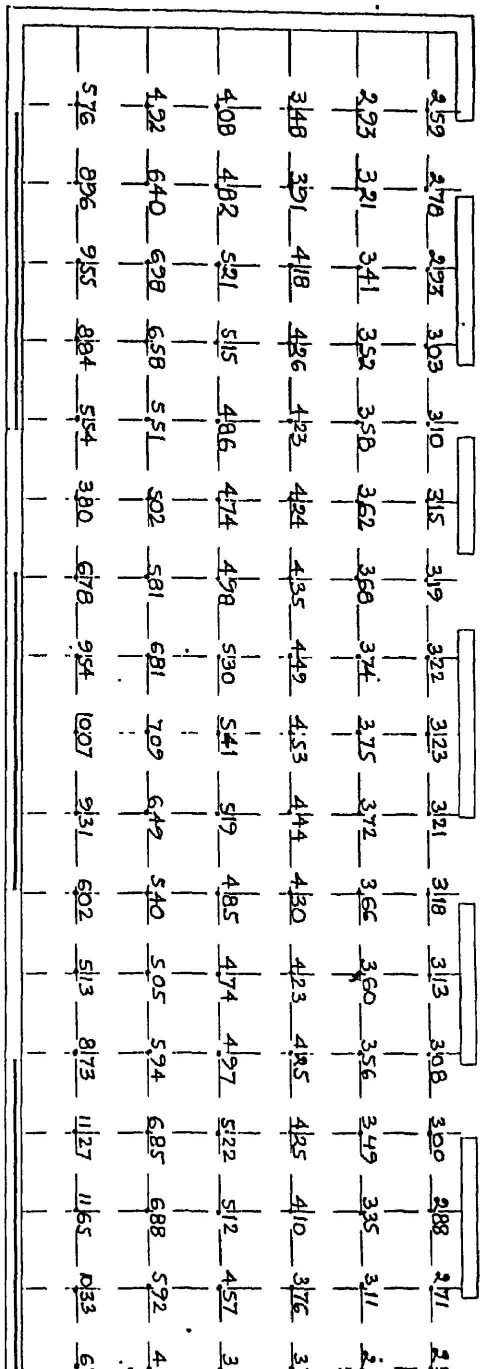
Table 3.7. Total (lighting + HVAC) consumption on a typical floor

Area	*Annual Energy Consumption (kWh)*	
	Proposed design with proposed shading	*Final Design (adopted)*
Lighting	20180	7170
HVAC	17352	15408
Total	37532	22578
Saving	39.8%	

NORTH FACING LABORATORY



SECTION OF THE WINDOW (enlarged)

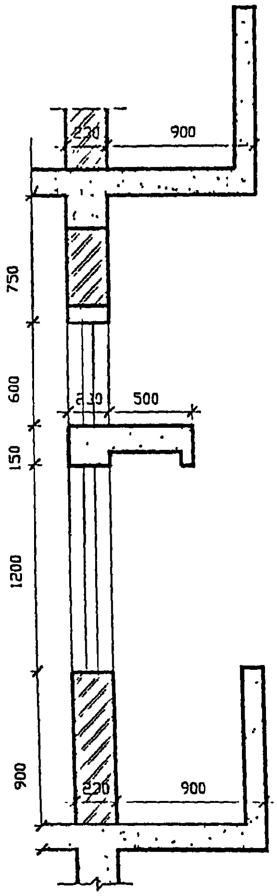


PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF 2M

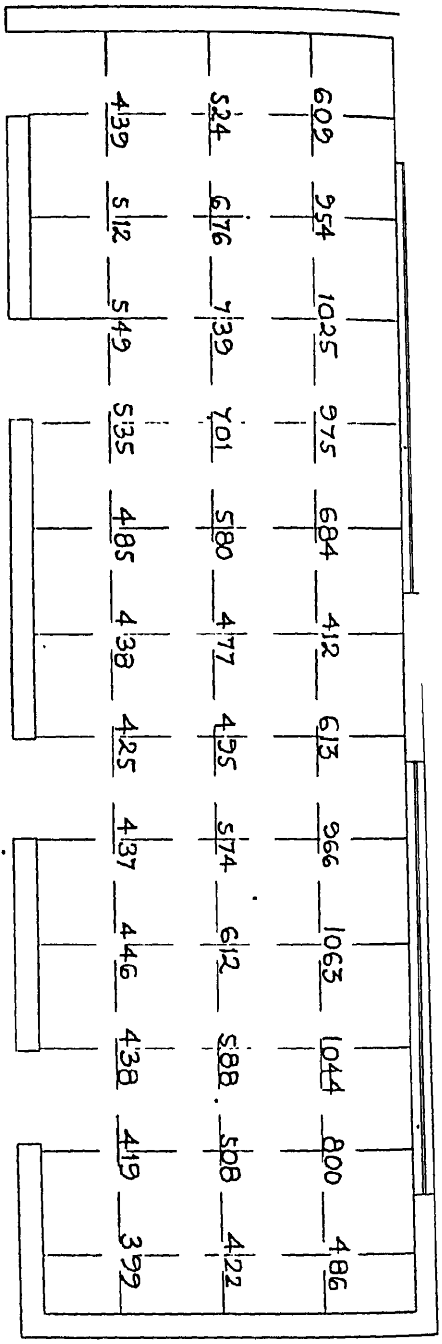
CASE 1 : PROPOSED WINDOW PROPOSED SHADING

Fig 3.1

SOUTH FACING LABORATORY



SECTION OF THE WINDOW (enlarged)



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERV

CASE 1 : PROPOSED WINDOW PROPOSED SHADING

Fig 3.2

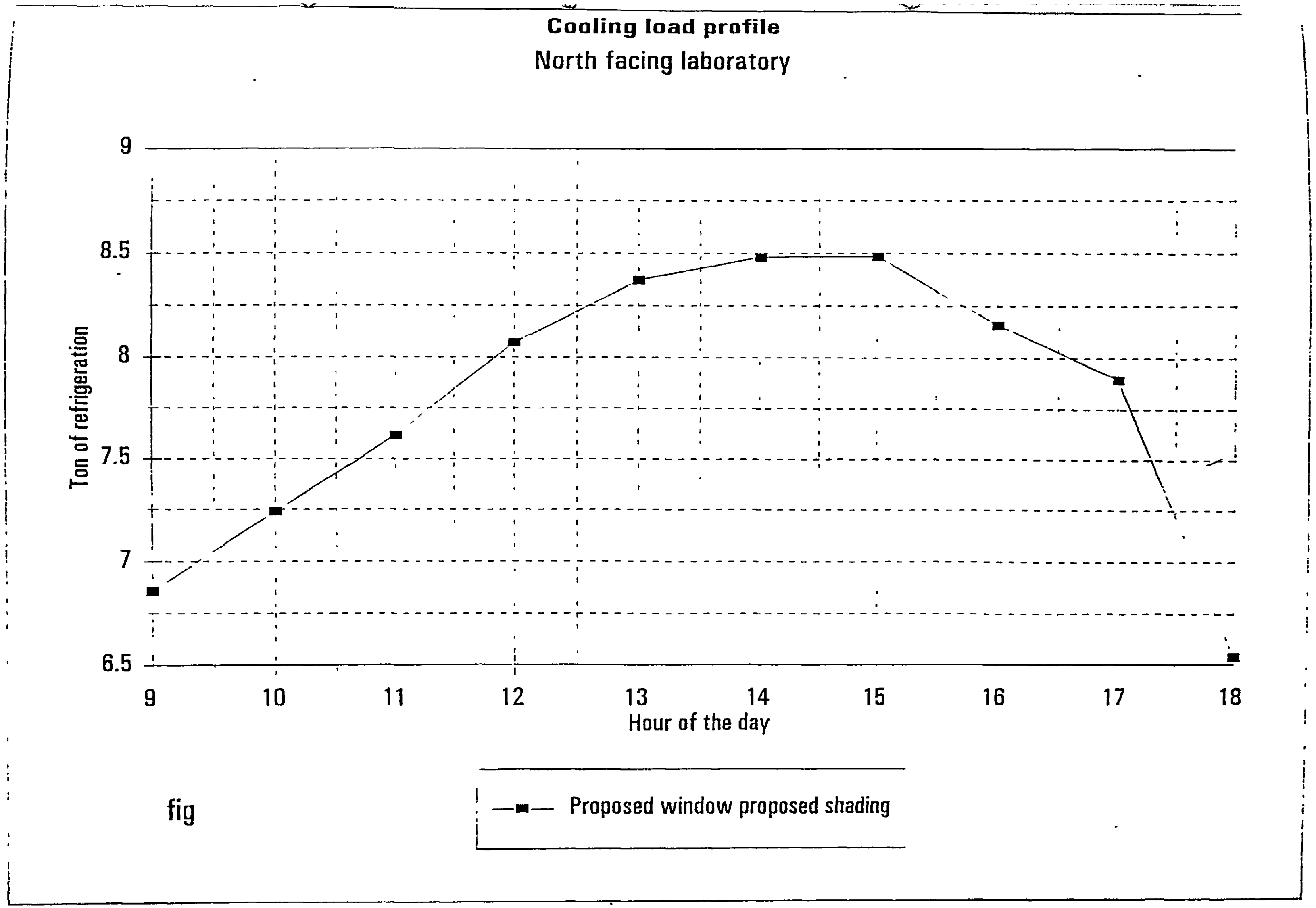

Cooling load profile
North facing laboratory
9
8.5
8
7.5
7
6.5
Ton of refrigeration
9
10
11
12
13
14
15
16
17
18
Hour of the day
fig
Proposed window proposed shading

Fig 3.3

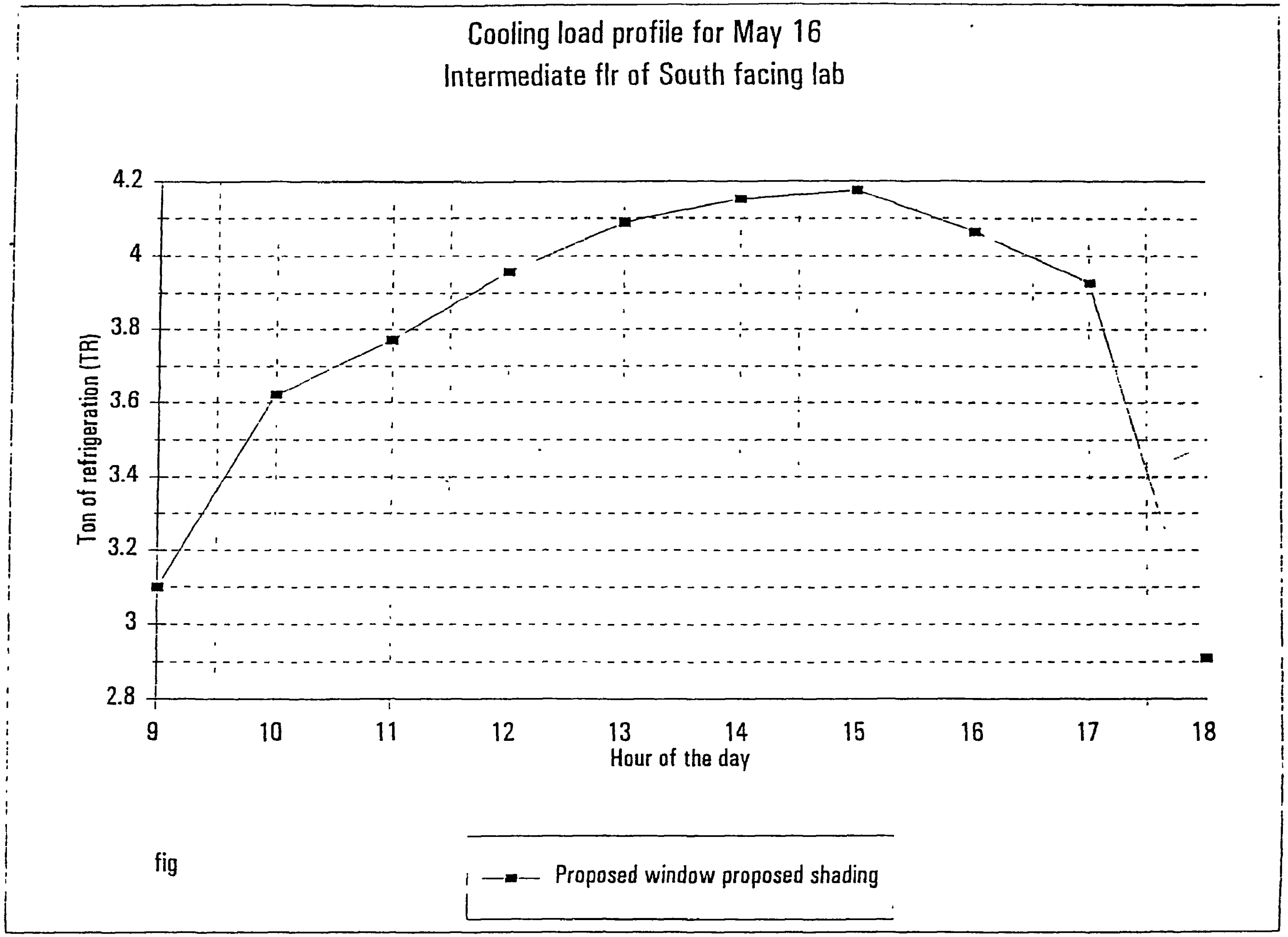
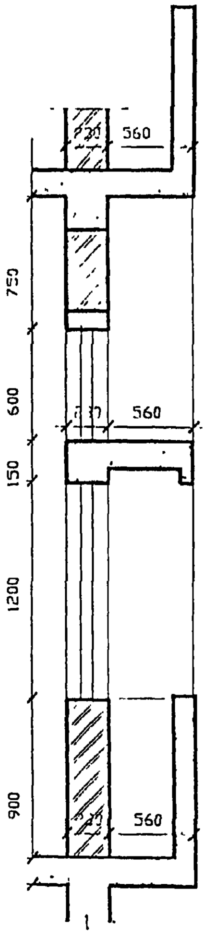
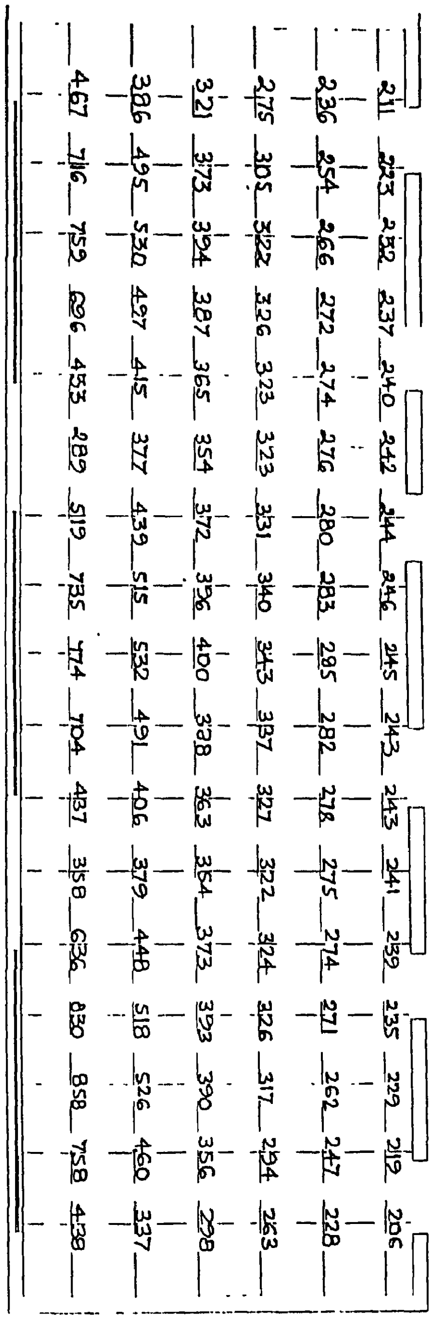

Cooling load profile for May 16
Intermediate flr of South facing lab
Ton of refrigeration (TR)
4.2
4
3.8
3.6
3.4
3.2
3
2.8
9
10
11
12
13
14
15
16
17
18
Hour of the day
fig
Proposed window proposed shading

Fig 3.4

NORTH FACING LABORATORY



SECTION OF THE WINDOW (enlarged)



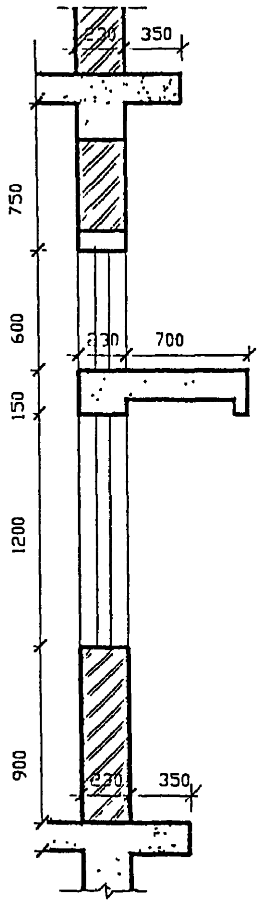
467	386	321	275	236	211
716	495	373	305	254	223
752	530	394	322	266	232
696	497	387	326	272	237
453	415	365	323	274	240
289	377	354	323	276	242
519	439	372	331	280	244
735	515	396	340	283	246
774	532	400	343	285	245
704	491	398	337	282	243
437	406	363	327	278	243
358	379	354	322	275	241
636	448	373	324	274	239
830	518	393	326	271	235
858	526	390	317	262	229
758	460	356	294	247	219
438	337	298	263	228	206

PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF 2M

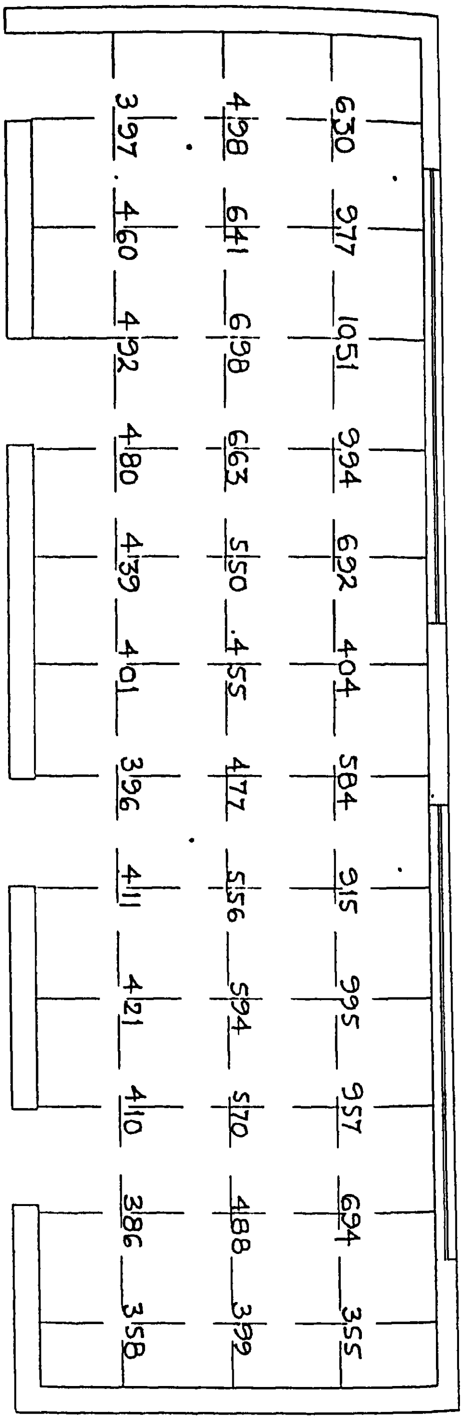
CASE 2 : PROPOSED WINDOW MODIFIED SHADING

Fig 3.5

SOUTH FACING LABORATORY



SECTION OF THE WINDOW (enlarged)



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERV

CASE 2 : PROPOSED WINDOW MODIFIED SHADING

Fig 3.6

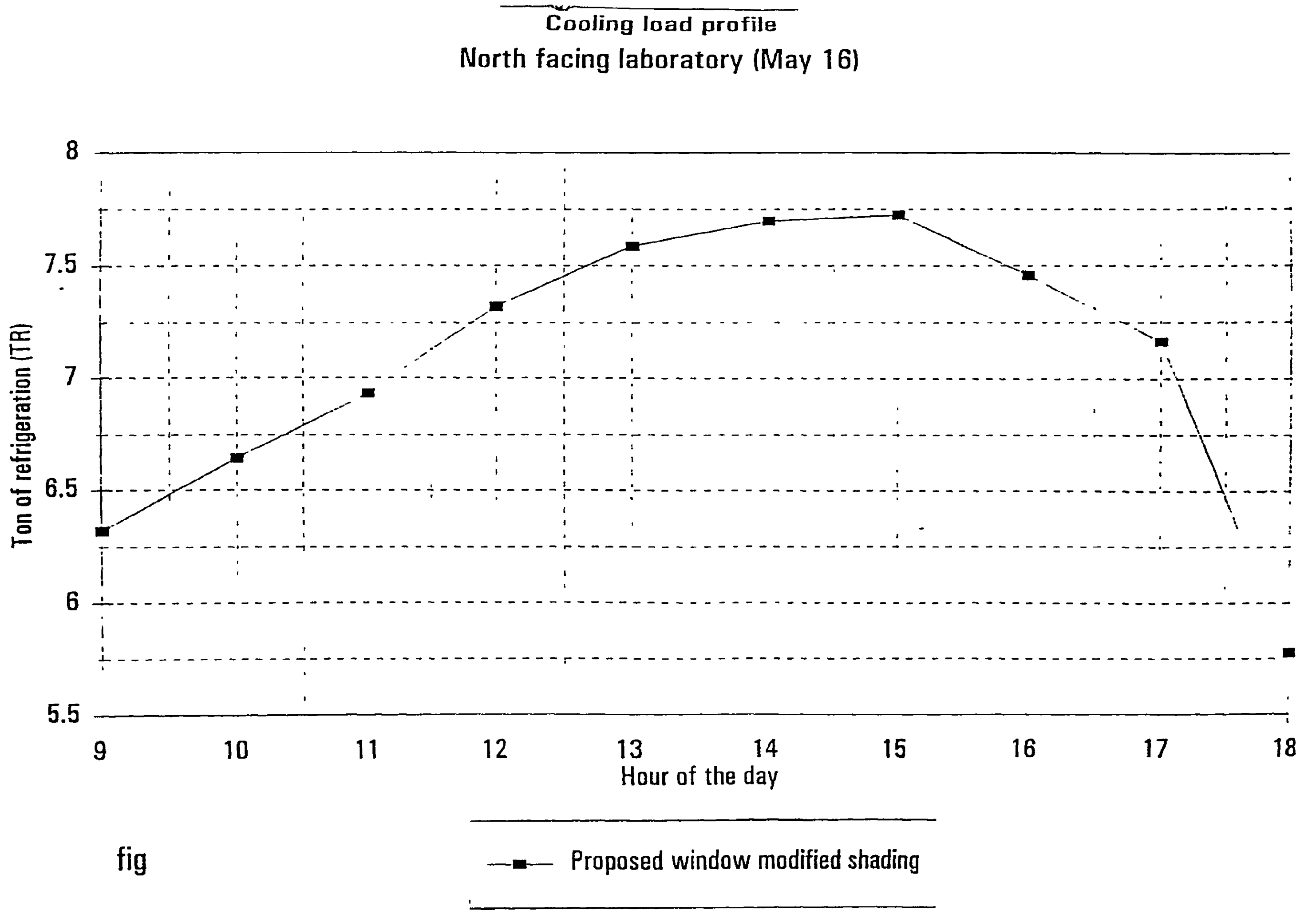


Fig 3.7

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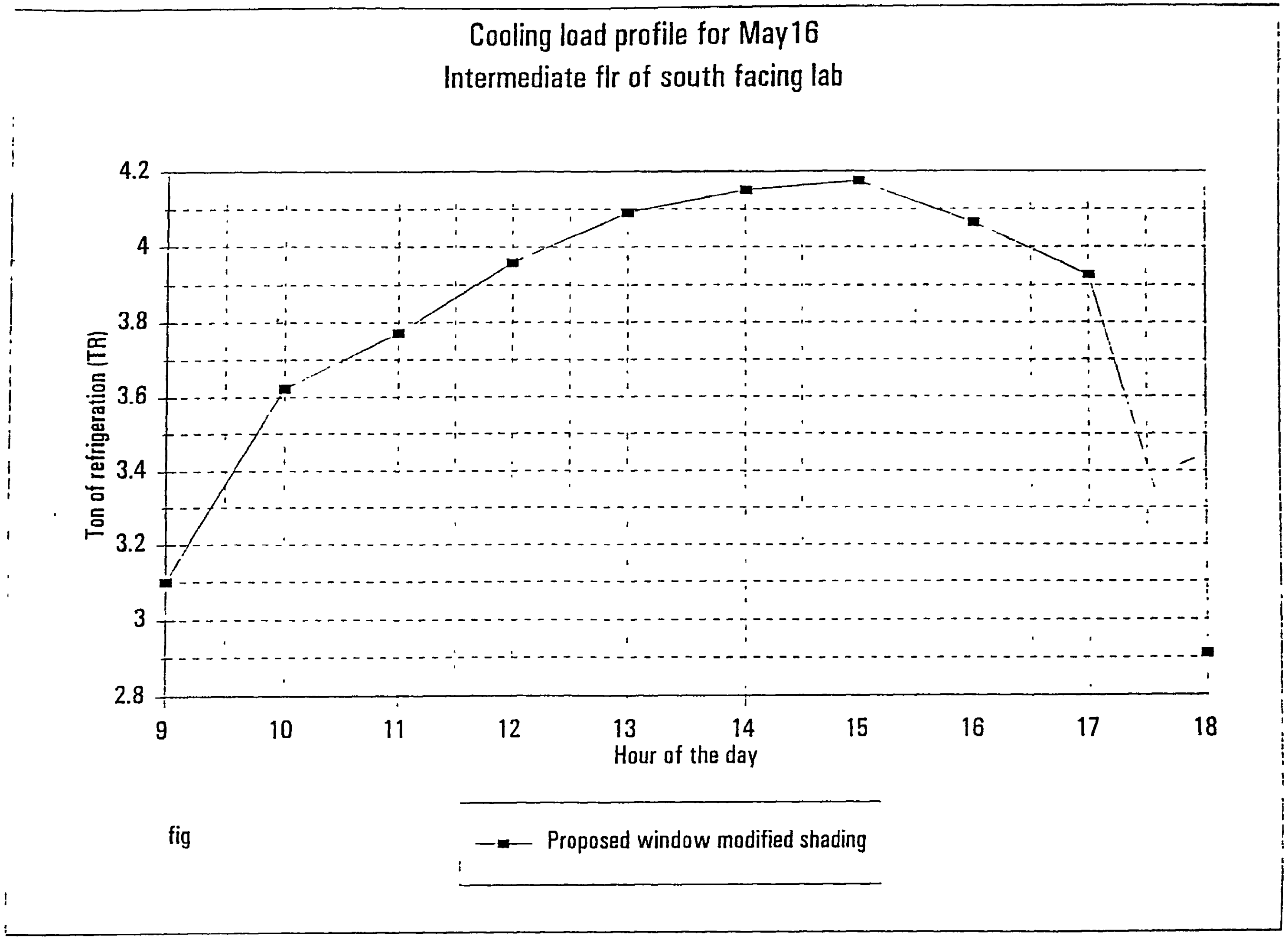
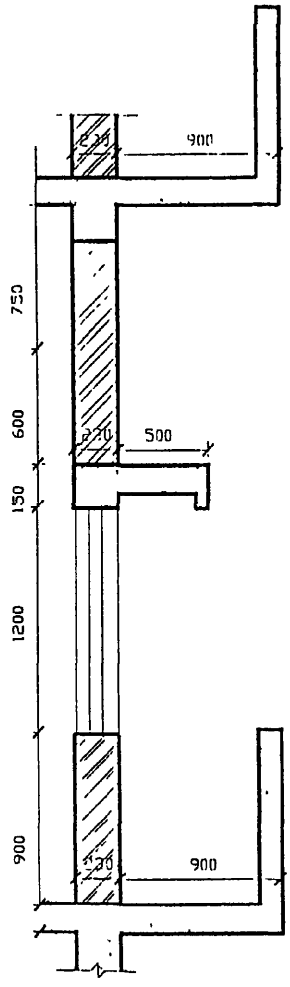
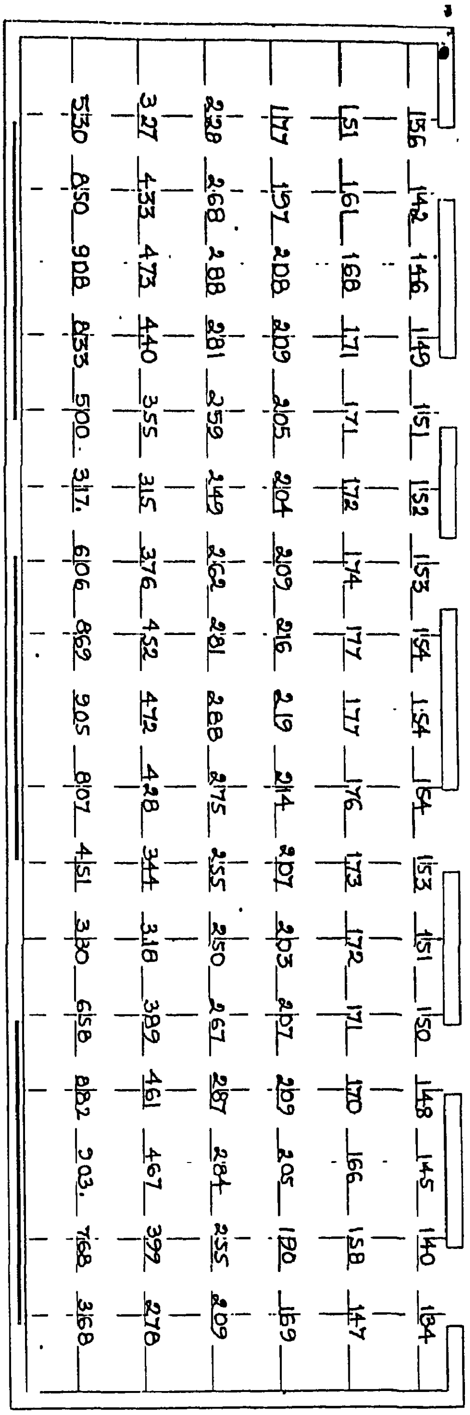

Cooling load profile for May16
Intermediate flr of south facing lab
Ton of refrigeration (TR)
4.2
4
3.8
3.6
3.4
3.2
3
2.8
9
10
11
12
13
14
15
16
17
18
Hour of the day
fig
Proposed window modified shading

Fig 3.8

NORTH FACING LABORATORY



SECTION OF THE WINDOW (proposed)



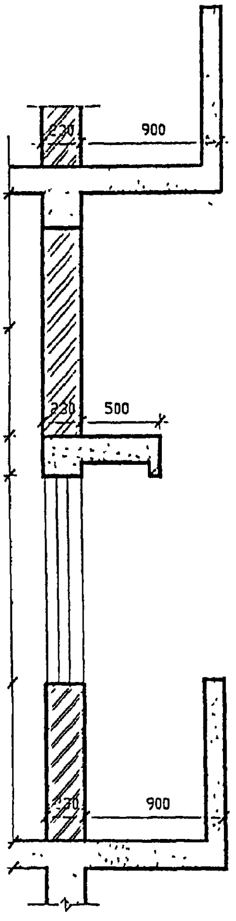
156	142	146	149	151	152	153	154	154	164	153	151	150	148	145	140	134
151	161	168	171	171	172	174	177	177	176	173	172	171	170	166	158	147
177	197	208	209	205	204	209	216	219	214	207	203	207	209	205	180	169
228	268	288	281	259	249	262	281	288	275	255	250	267	287	284	255	209
327	433	473	440	355	315	376	452	472	428	344	318	389	461	467	399	278
530	850	908	833	500	317	606	869	905	807	451	330	658	882	903	768	368

PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF 2M

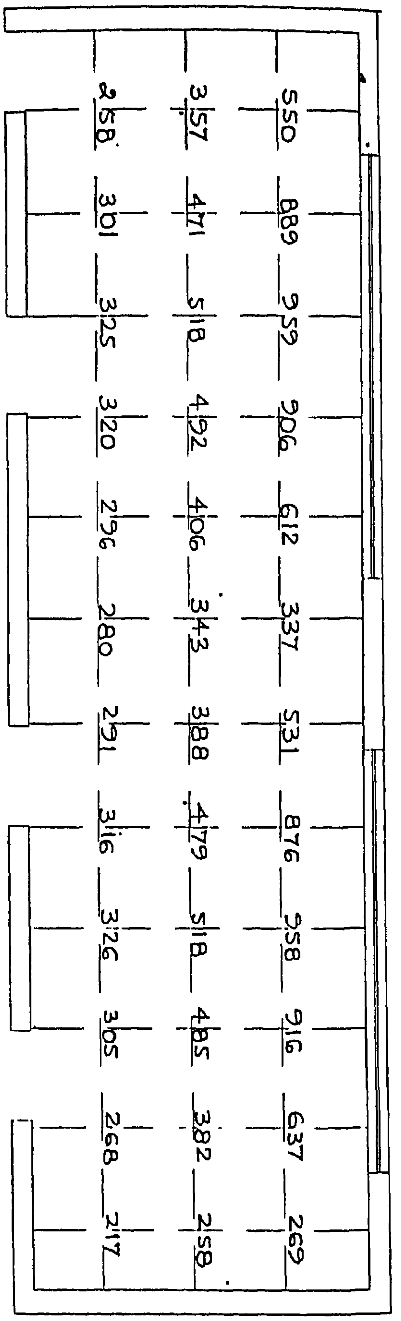
CASE 3 : MODIFIED WINDOW PROPOSED SHADING

Fig 3.9

SOUTH FACING LABORATORY



SECTION OF THE WINDOW (enlarged)



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF

Cooling load profile

North facing laboratory (May 16)

CASE 3 : MODIFIED WINDOW PROPOSED SHADING

Fig 3.10

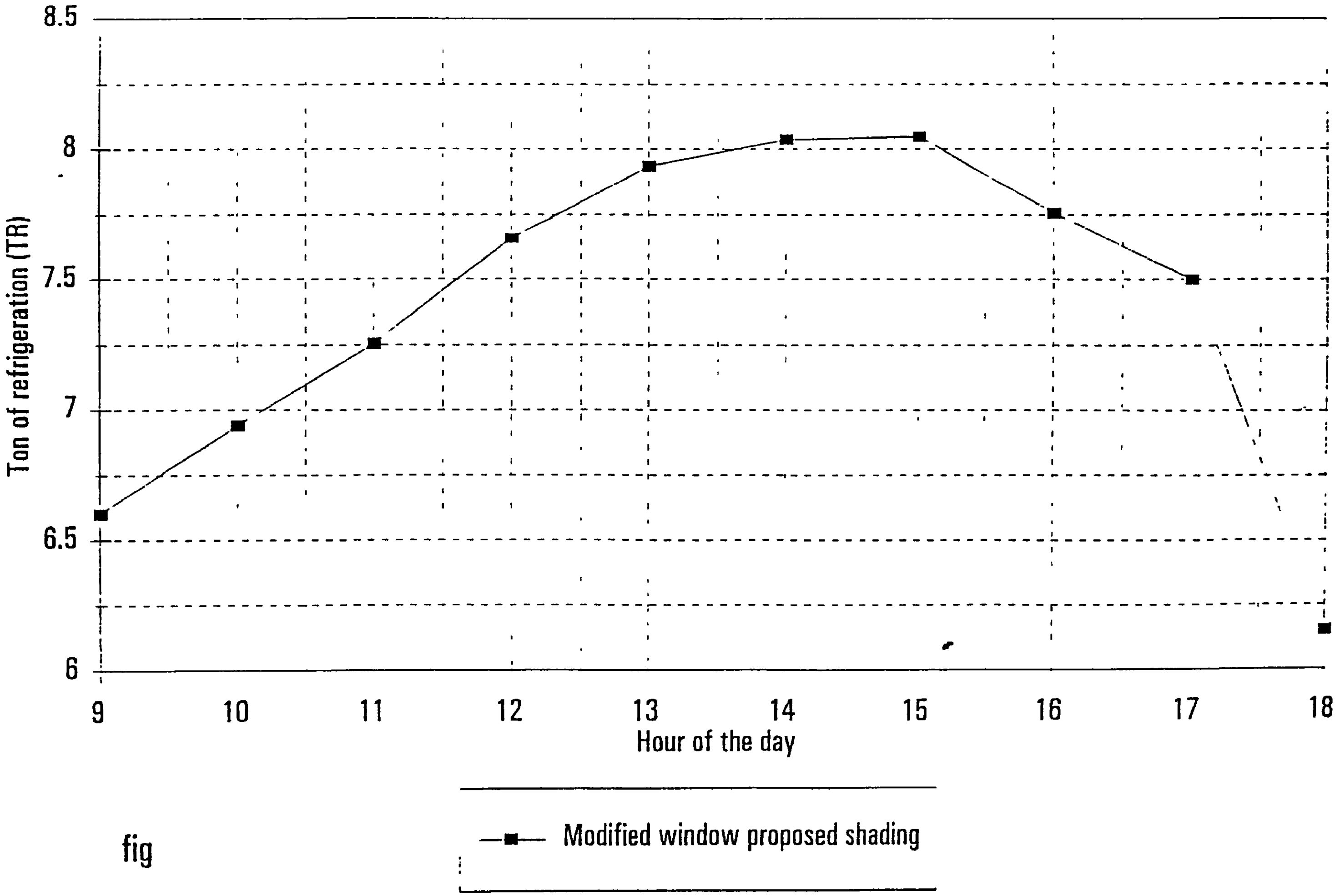


Fig 3.11

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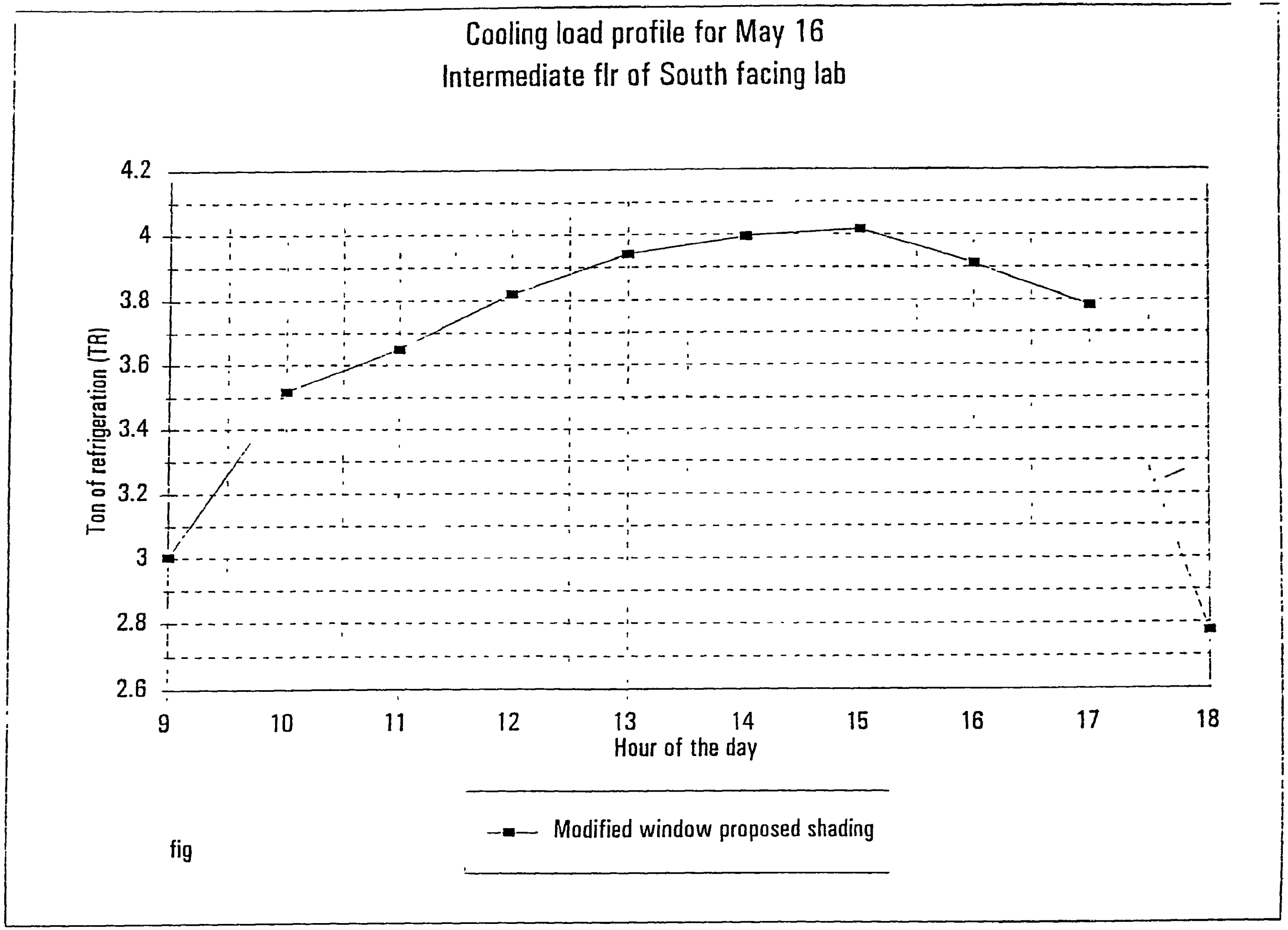
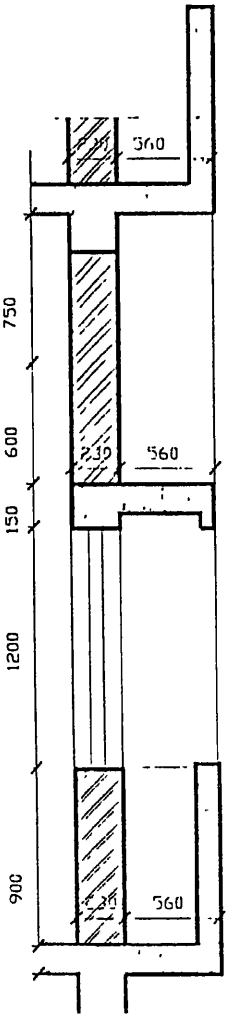
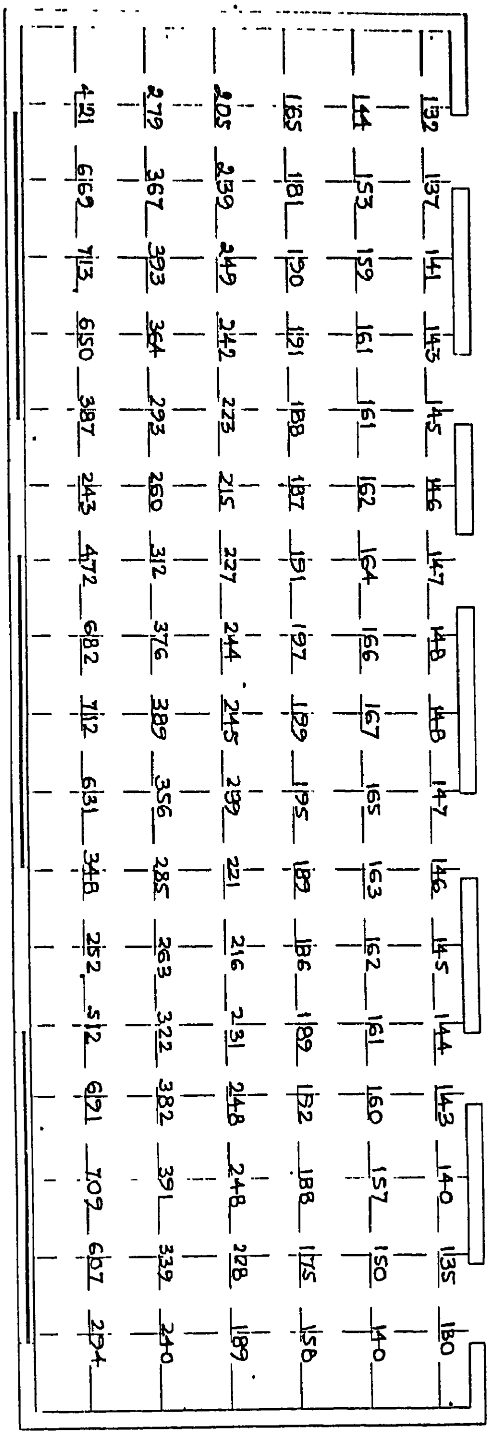

Cooling load profile for May 16
Intermediate flr of South facing lab
Ton of refrigeration (TR)
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
9
10
11
12
13
14
15
16
17
18
Hour of the day
Modified window proposed shading
fig

Fig 3.12

NORTH FACING LABORATORY



SECTION OF THE WINDOW (enlarged)



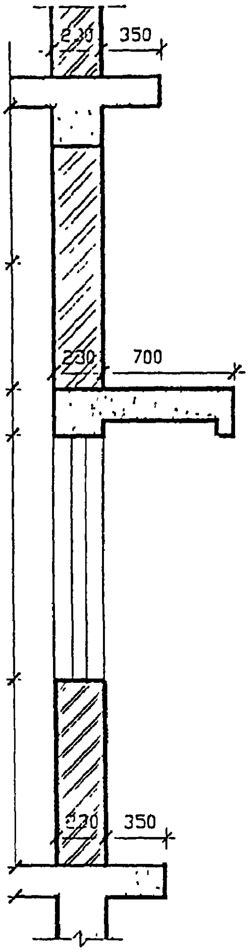
PLAN SHOWING DAYLIGHT LEVELS (LUX) AT REGULAR INTERVALS

132	137	141	143	145	146	147	148	148	147	146	145	144	143	140	135	180
144	153	159	161	161	162	164	166	167	165	163	162	161	160	157	150	140
165	181	190	191	188	187	191	197	199	195	189	186	189	192	188	175	158
205	239	249	242	223	215	227	244	245	299	221	216	231	248	248	228	189
279	367	393	364	293	260	312	376	389	356	285	263	322	382	391	339	240
421	669	713	650	387	243	472	682	712	631	348	252	512	621	709	607	294

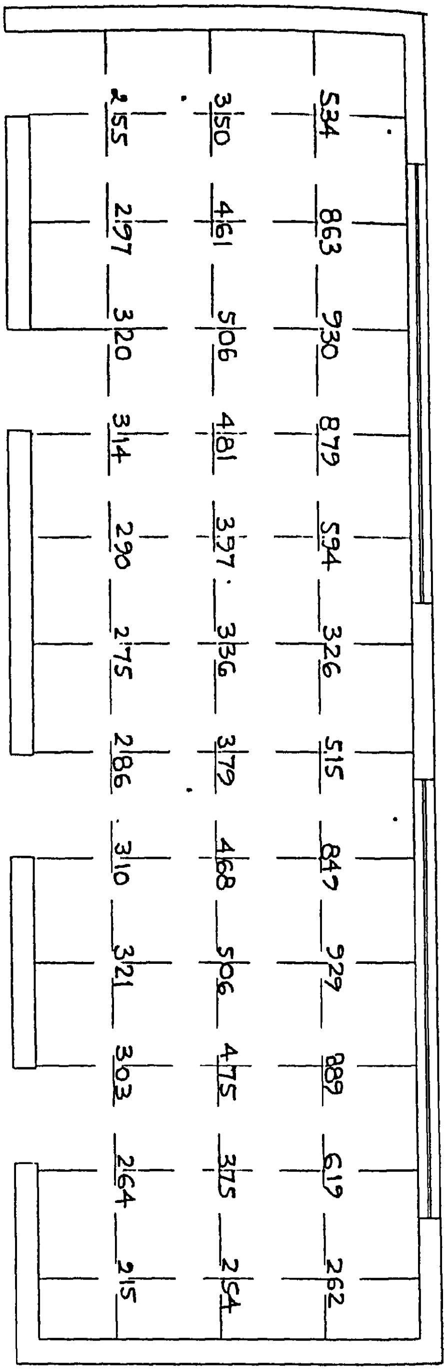
CASE 4 : MODIFIED WINDOW MODIFIED SHADING

Fig 3.13

SOUTH FACING LABORATORY



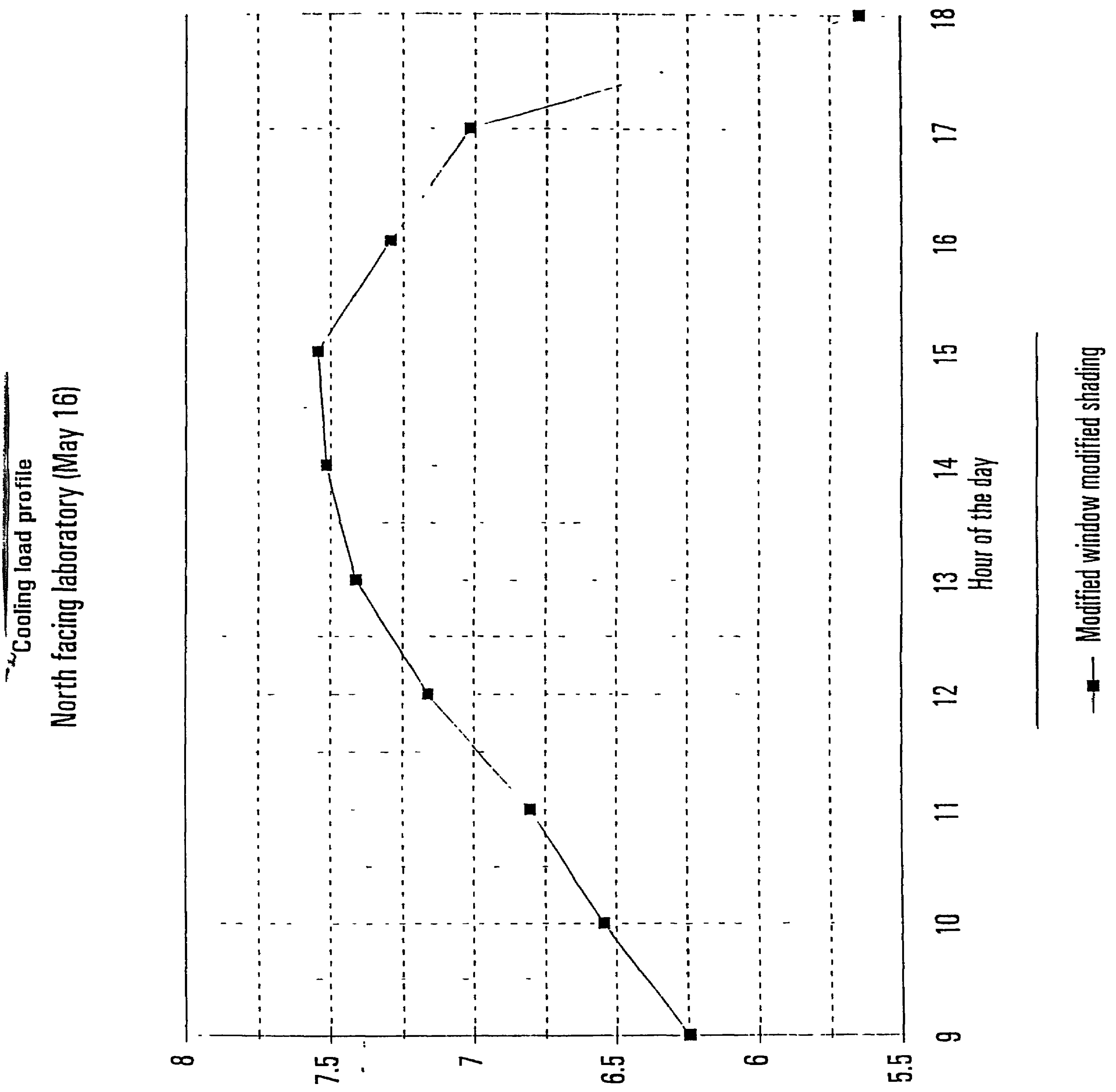
SECTION OF THE WINDOW (enlarged)



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL

CASE 4 : MODIFIED WINDOW MODIFIED SHADIN

Fig 3.14


Cooling load profile
North facing laboratory (May 16)
Ton of refrigeration (TR)
8
7.5
7
6.5
6
5.5
9
10
11
12
13
14
15
16
17
18
Hour of the day
Modified window modified shading

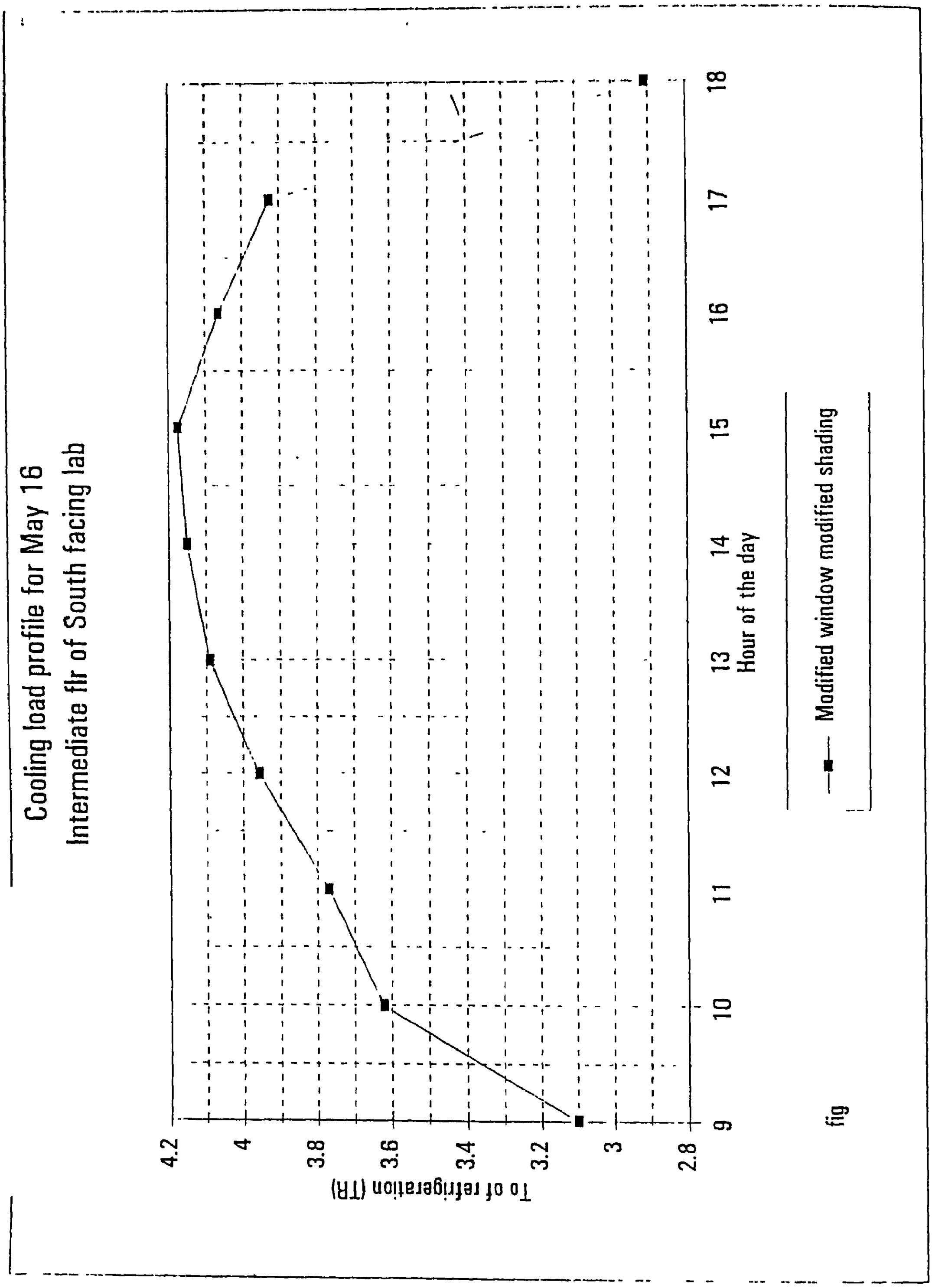
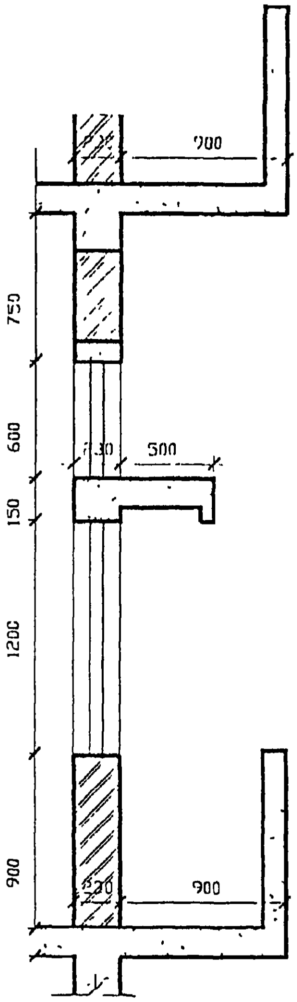
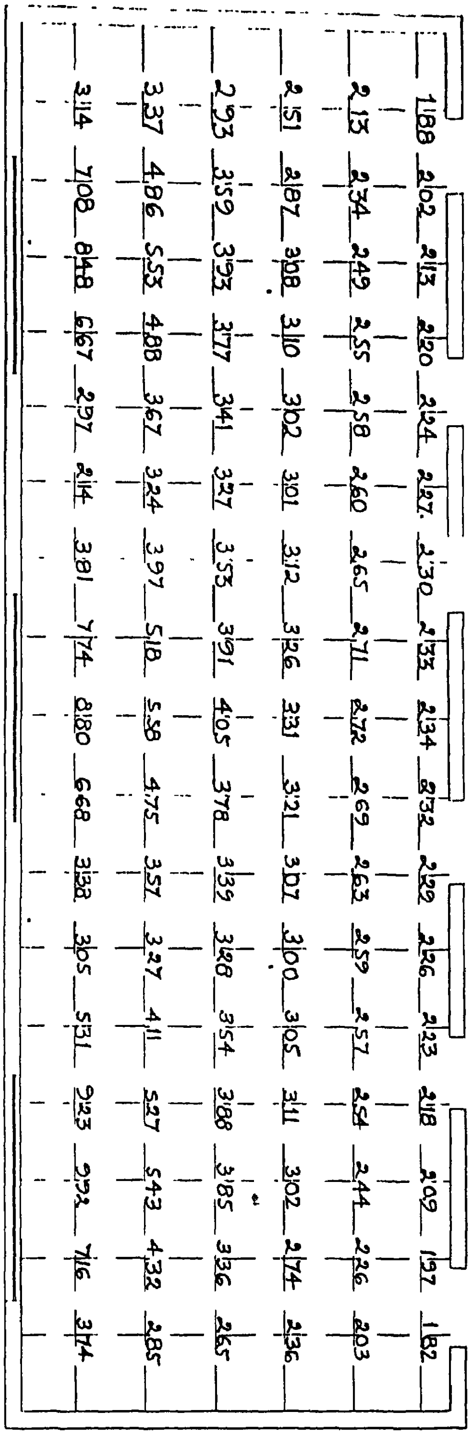

Cooling load profile for May 16
Intermediate flr of South facing lab
To of refrigeration (TR)
4.2
4
3.8
3.6
3.4
3.2
3
2.8
9
10
11
12
13
14
15
16
17
18
Hour of the day
Modified window modified shading
fig

Fig 3.16

NORTH FACING LABORATORY



SECTION OF THE WINDOW (enlarged)



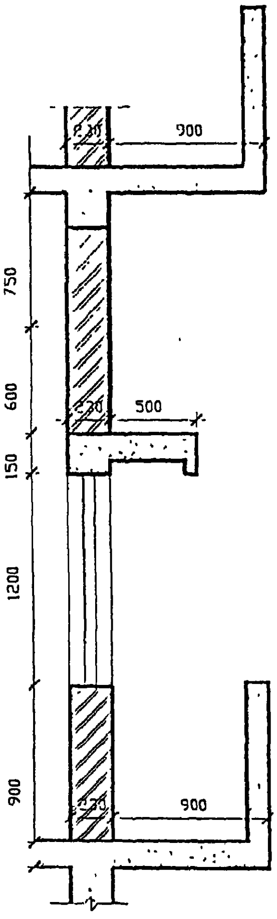
1.88	2.02	2.13	2.20	2.24	2.27	2.30	2.33	2.34	2.32	2.22	2.26	2.23	2.18	2.09	1.97	1.82
2.13	2.34	2.49	2.55	2.58	2.60	2.65	2.71	2.72	2.69	2.63	2.59	2.57	2.54	2.44	2.26	2.03
2.51	2.87	3.08	3.10	3.02	3.01	3.12	3.26	3.31	3.21	3.07	3.00	3.05	3.11	3.02	2.74	2.36
2.93	3.59	3.93	3.77	3.41	3.27	3.53	3.91	4.05	3.78	3.39	3.28	3.54	3.88	3.85	3.36	2.65
3.37	4.86	5.53	4.88	3.67	3.24	3.97	5.18	5.58	4.75	3.57	3.27	4.11	5.27	5.43	4.32	2.85
3.14	7.08	8.48	6.67	2.97	2.14	3.81	7.74	8.80	6.68	3.38	3.05	5.31	9.23	9.92	7.16	3.74

PLAN SHOWING DAYLIGHT LEVELS (LUX) AT REGULAR INTERVALS

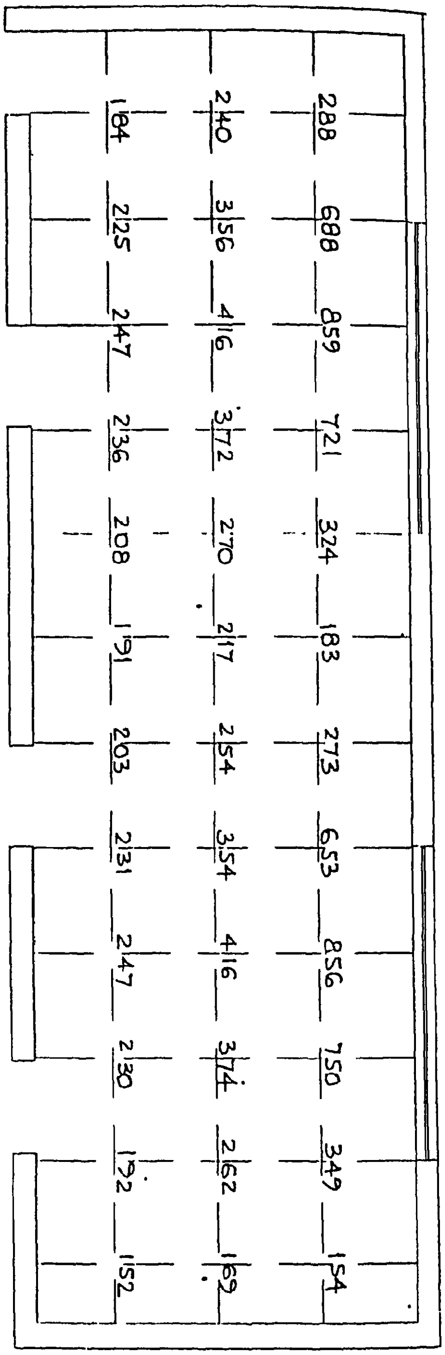
CASE 5 : RECOMMENDED WINDOW PROPOSED SHADING

Fig 3.17

SOUTH FACING LABORATORY



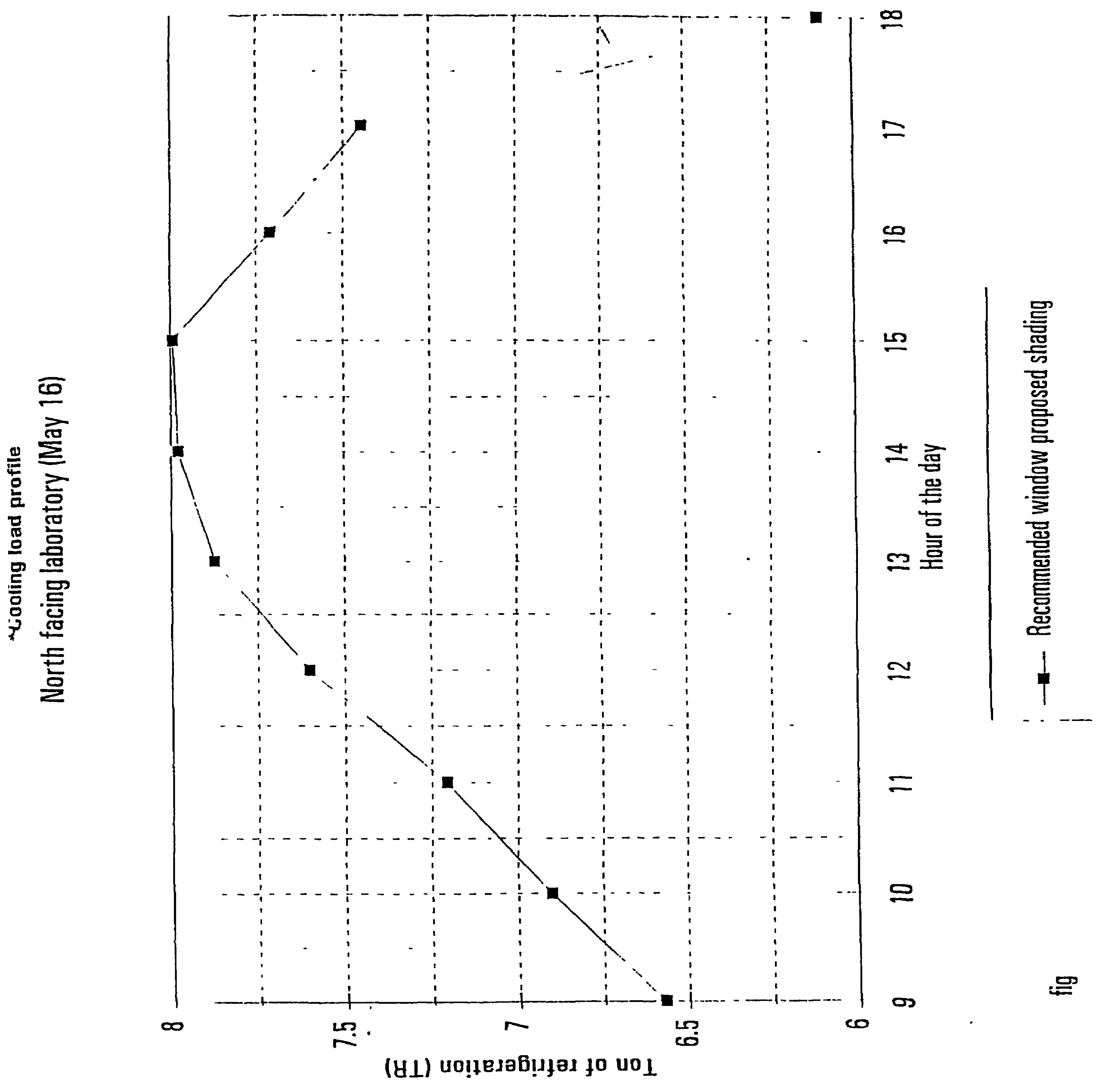
SECTION OF THE WINDOW (enlarged)



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL

CASE 5 : RECOMMENDED WINDOW PROPOSED SHAD

Fig 3 18


*Cooling load profile
North facing laboratory (May 16)
Ton of refrigeration (TR)
8
7.5
7
6.5
6
Hour of the day
9
10
11
12
13
14
15
16
17
18
Recommended window proposed shading
fig

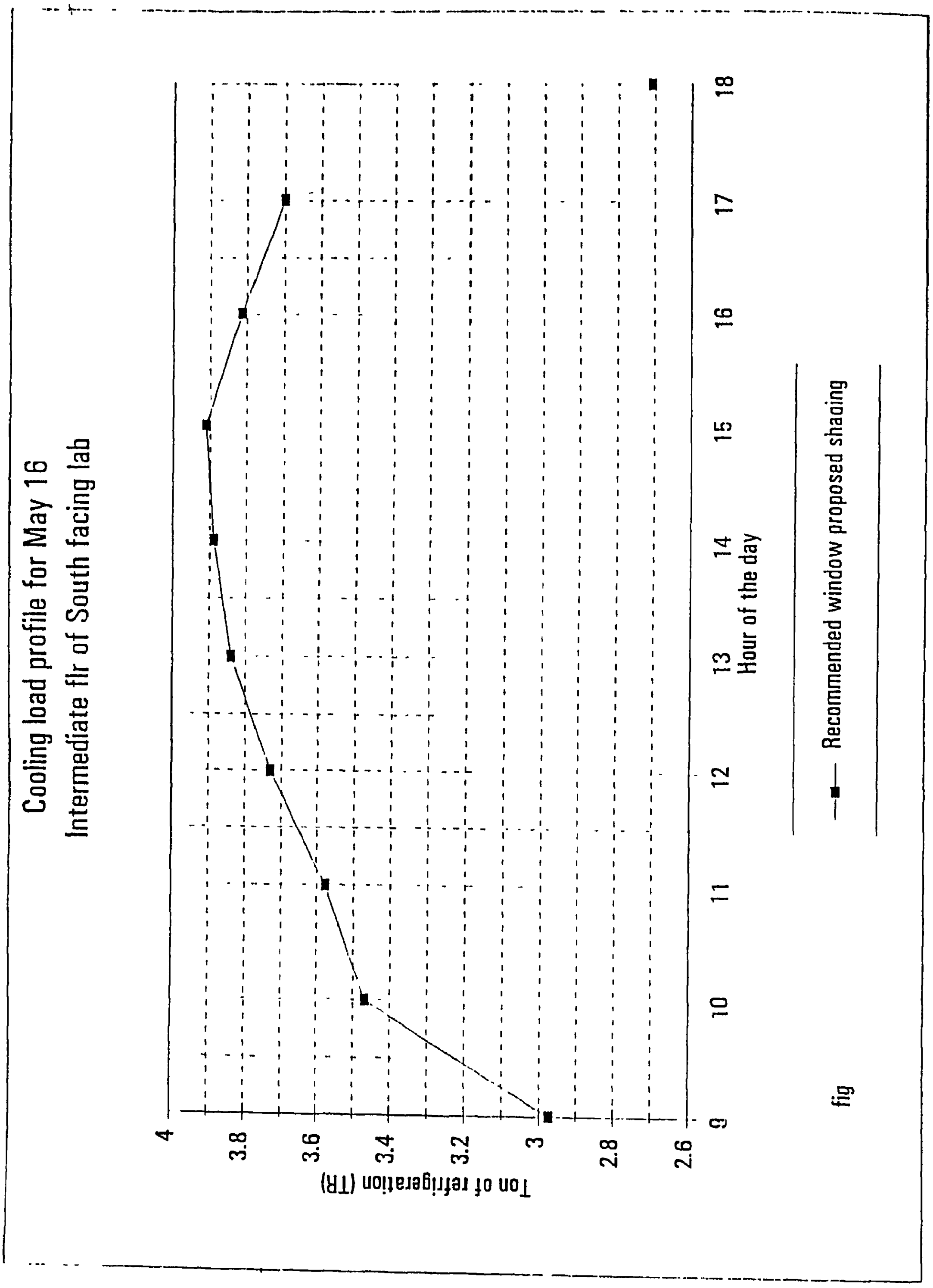
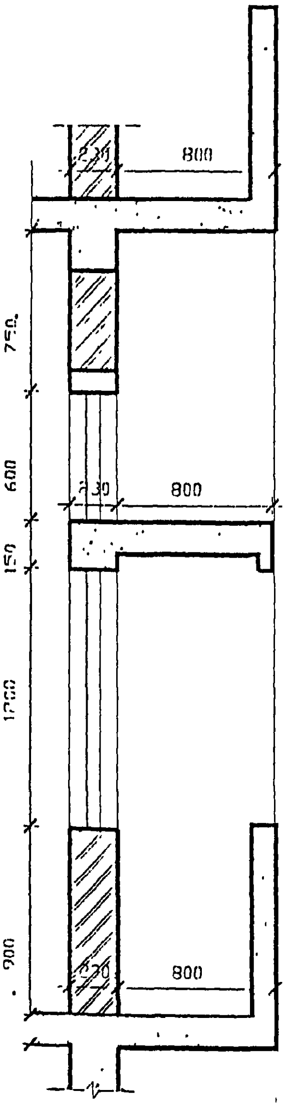
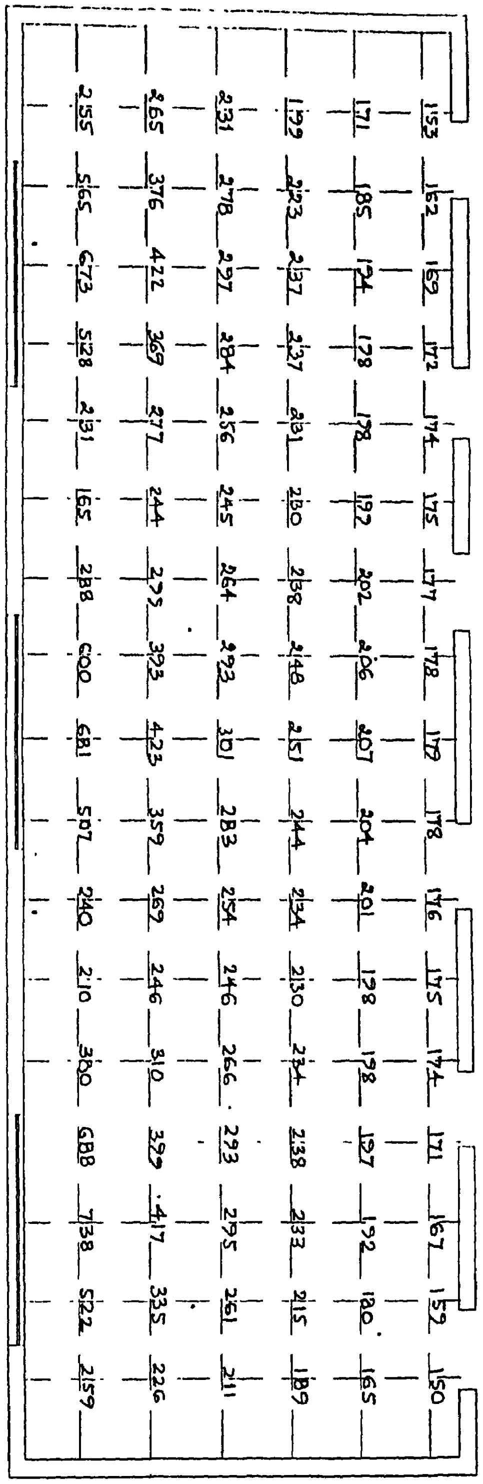

Cooling load profile for May 16
Intermediate flr of South facing lab
Ton of refrigeration (TR)
4
3.8
3.6
3.4
3.2
3
2.8
2.6
9
10
11
12
13
14
15
16
17
18
Hour of the day
fig
Recommended window proposed shading

Fig 3.20

NORTH FACING LABORATORY



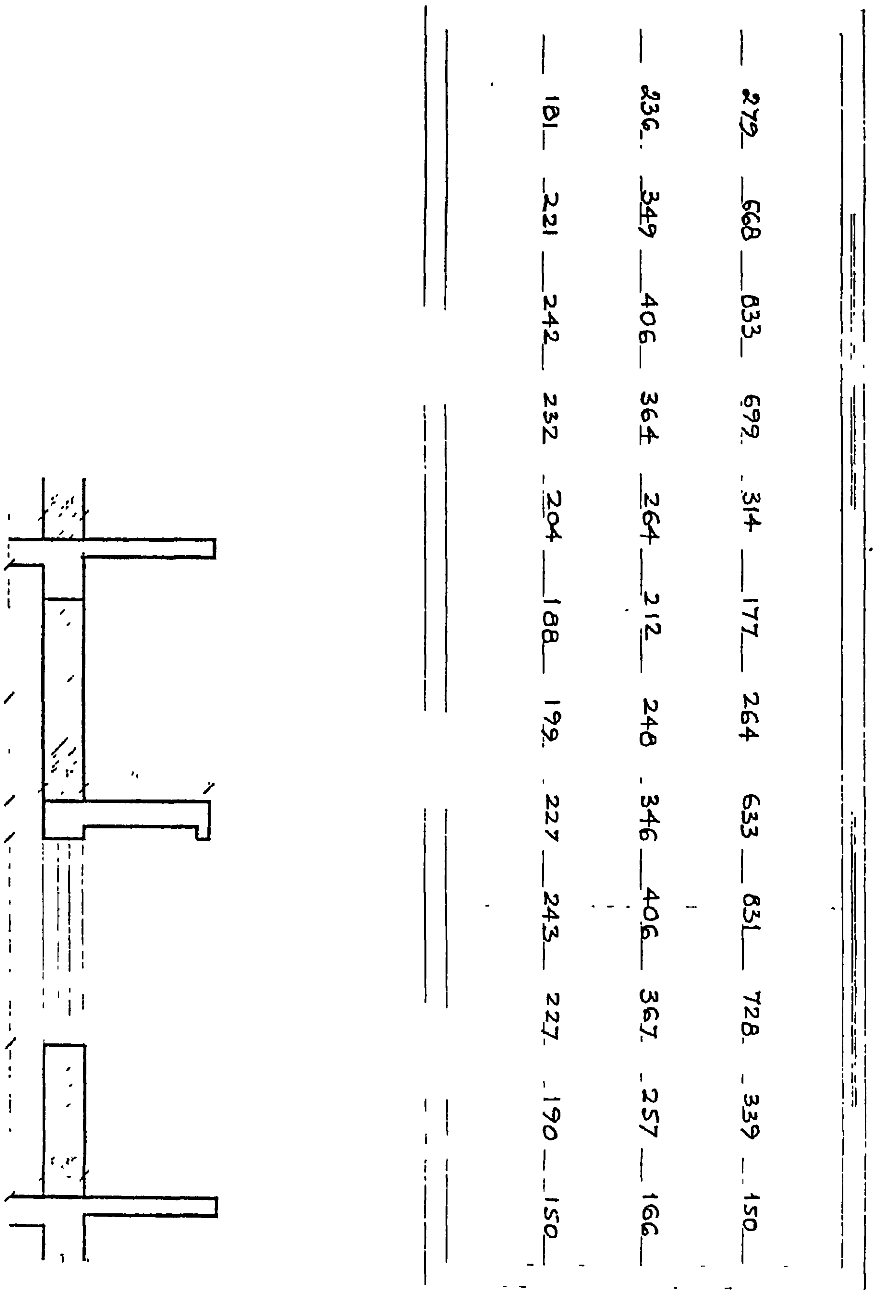
SECTION THROUGH WINDOW ([illegible])



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT REGULAR INTERVALS

CASE 6 : RECOMMENDED WINDOW RECOMMENDED SHADING

Fig 3.21



CASE - RECOMMENDED WINDOW RECOMMENDED SHADE

Fig 3.22

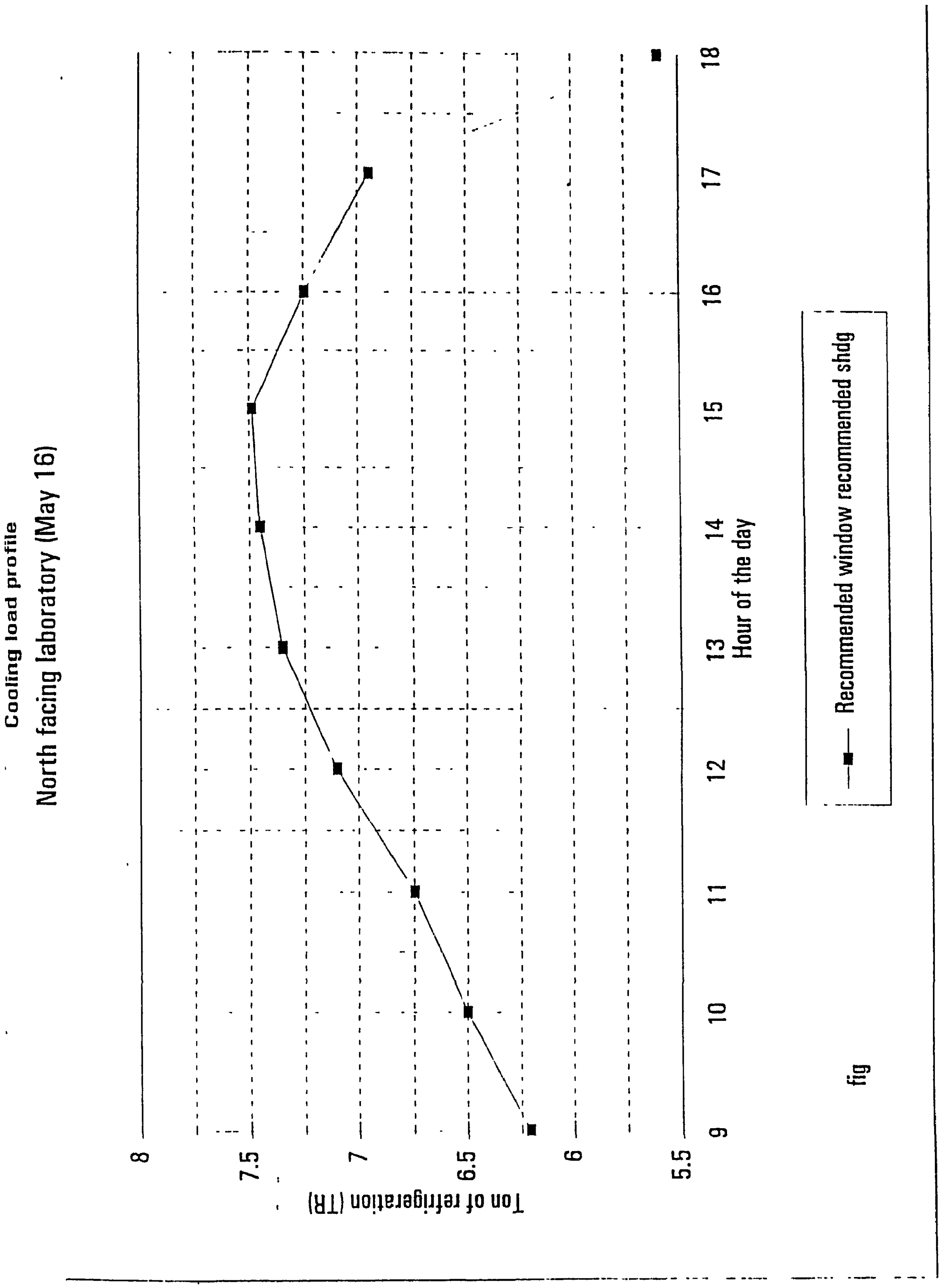


Fig 3.23

mls majumdar/bcg/lcn

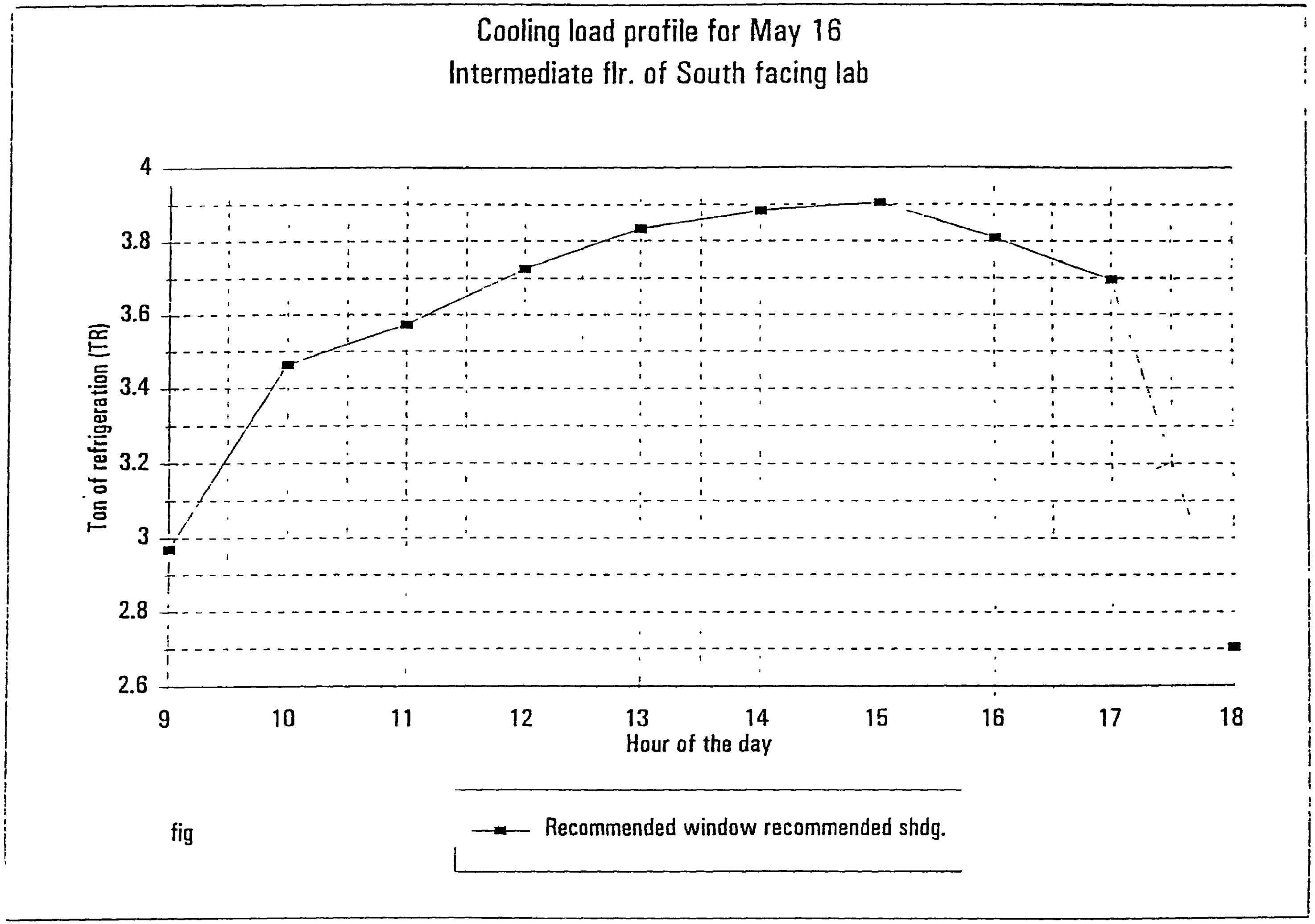
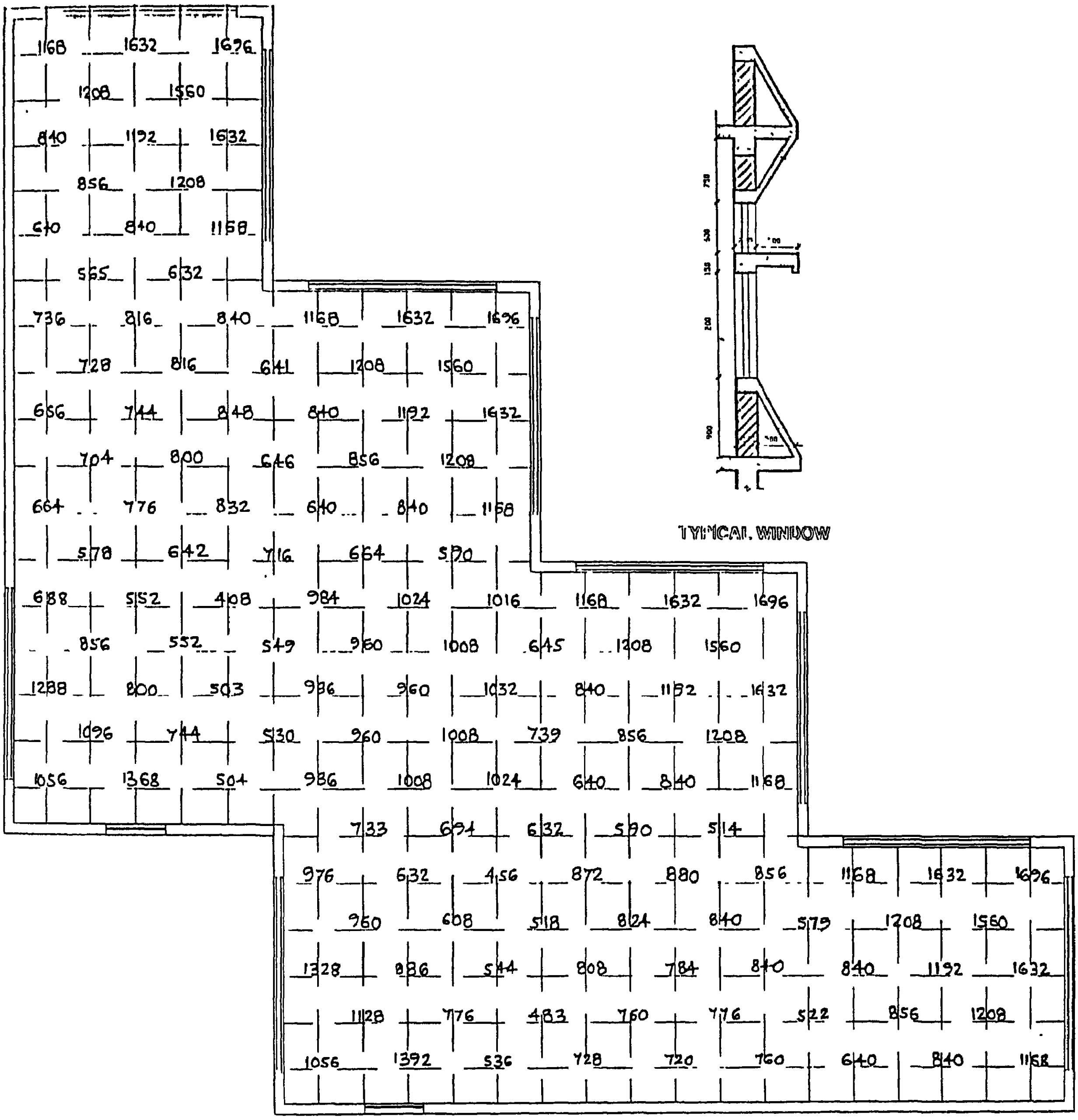

Cooling load profile for May 16
Intermediate flr. of South facing lab
Ton of refrigeration (TR)
4
3.8
3.6
3.4
3.2
3
2.8
2.6
9
10
11
12
13
14
15
16
17
18
Hour of the day
fig
Recommended window recommended shdg.

Fig 3.24

OFFICE SPACE



TYPICAL WINDOW

PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF 2M

CASE 1 PROPOSED WINDOW PROPOSED SHADING

Fig 3.25

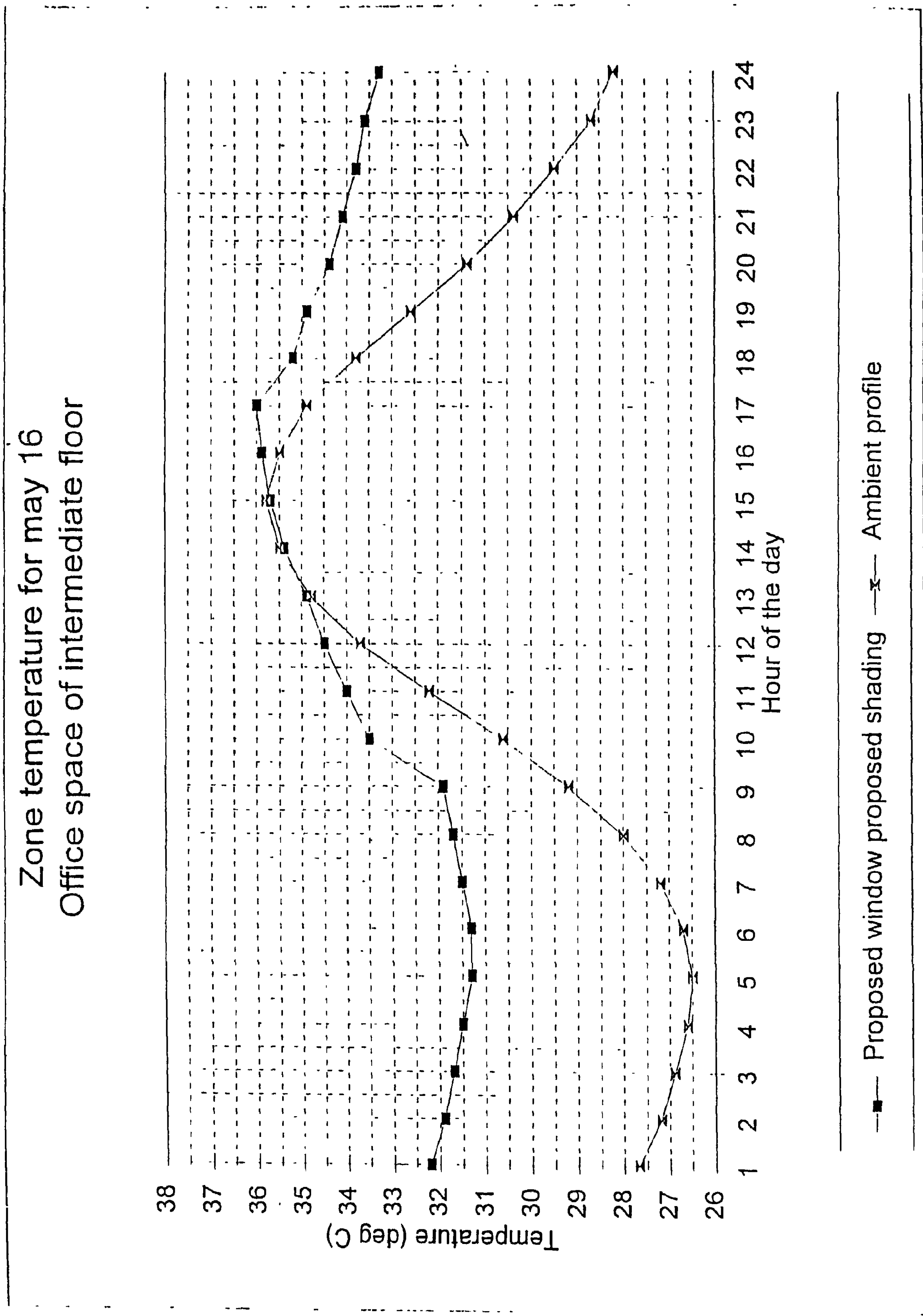
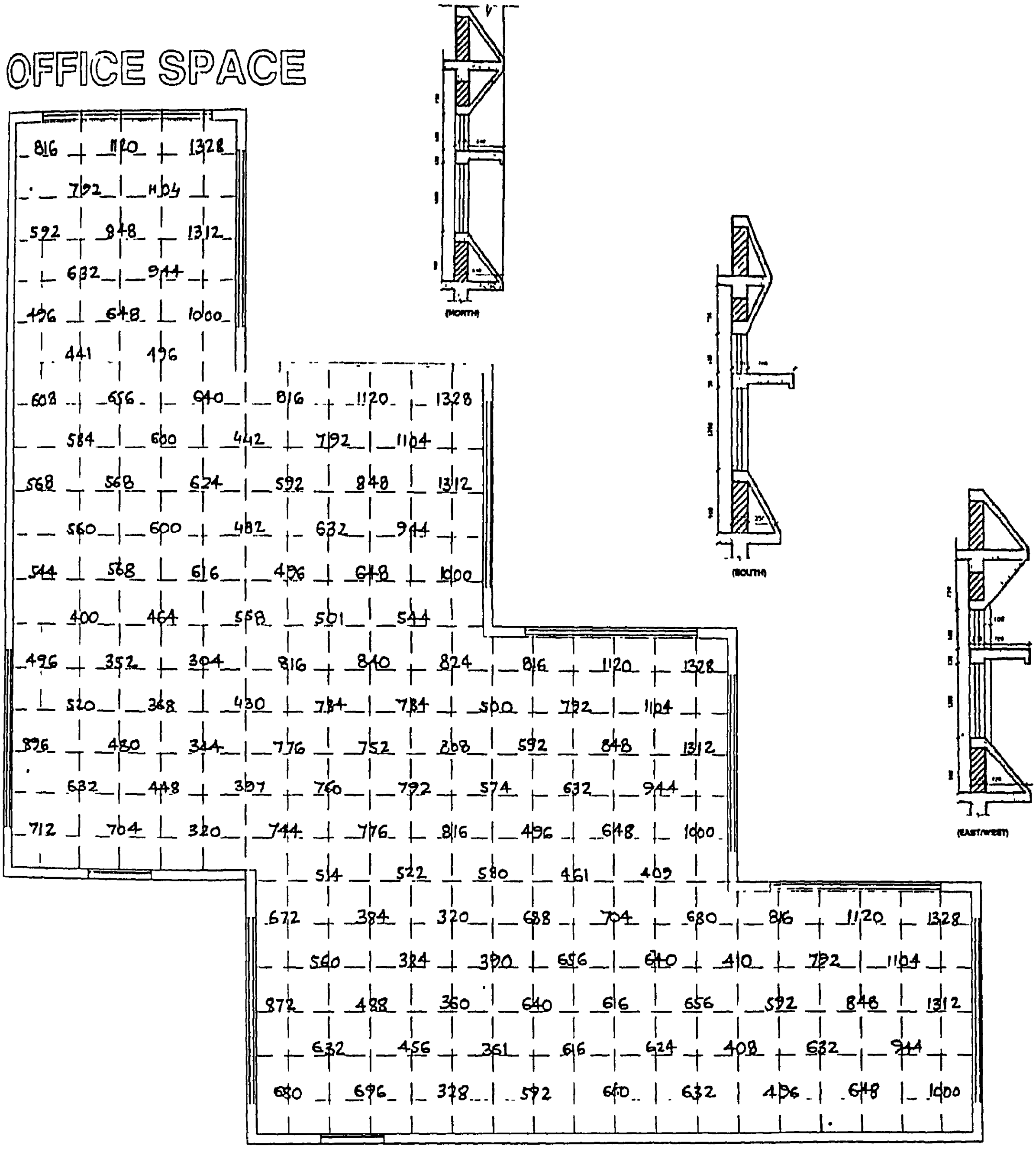

Zone temperature for may 16
Office space of intermediate floor
Temperature (deg C)
38
37
36
35
34
33
32
31
30
29
28
27
26
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Hour of the day
Proposed window proposed shading
Ambient profile

Fig 3.26



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF 2M

CASE 2 PROPOSED WINDOW MODIFIED SHADING

Fig 3.27

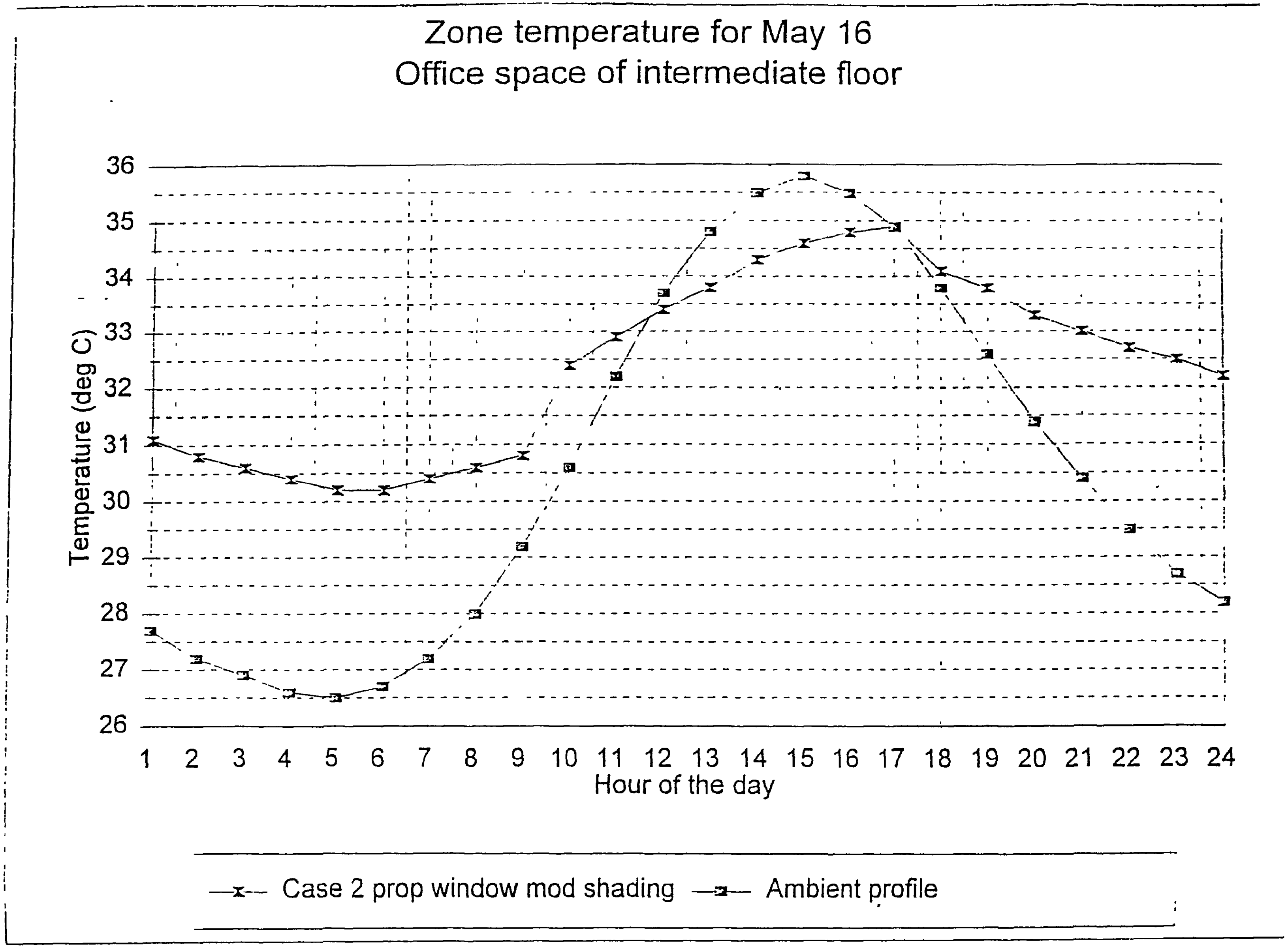
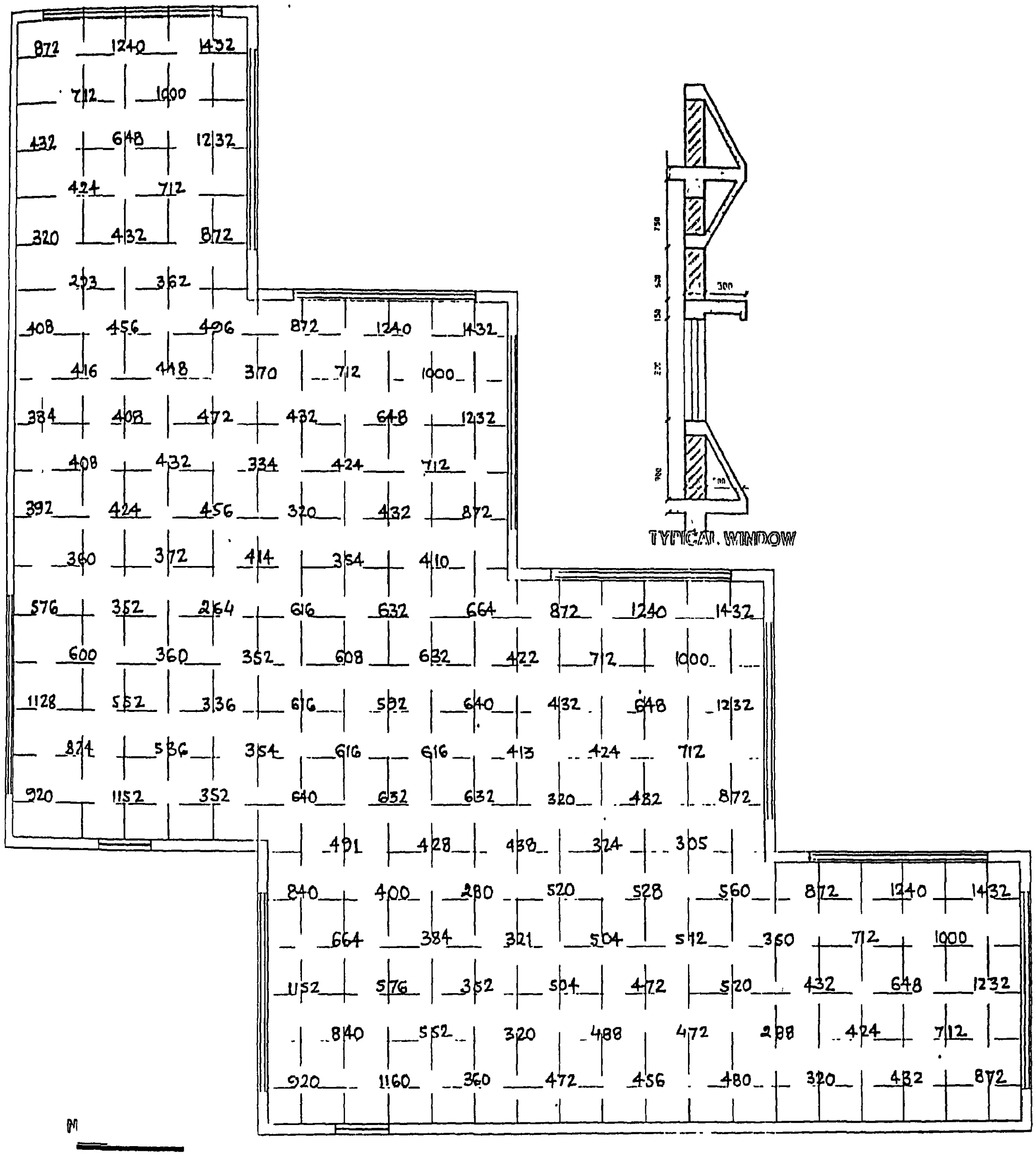

Zone temperature for May 16
Office space of intermediate floor
Temperature (deg C)
36
35
34
33
32
31
30
29
28
27
26
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Hour of the day
Case 2 prop window mod shading
Ambient profile

Fig 3.28

OFFICE SPACE



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF 2M

CASE 3 MODIFIED WINDOW PROPOSED SHADING

Fig 3.29

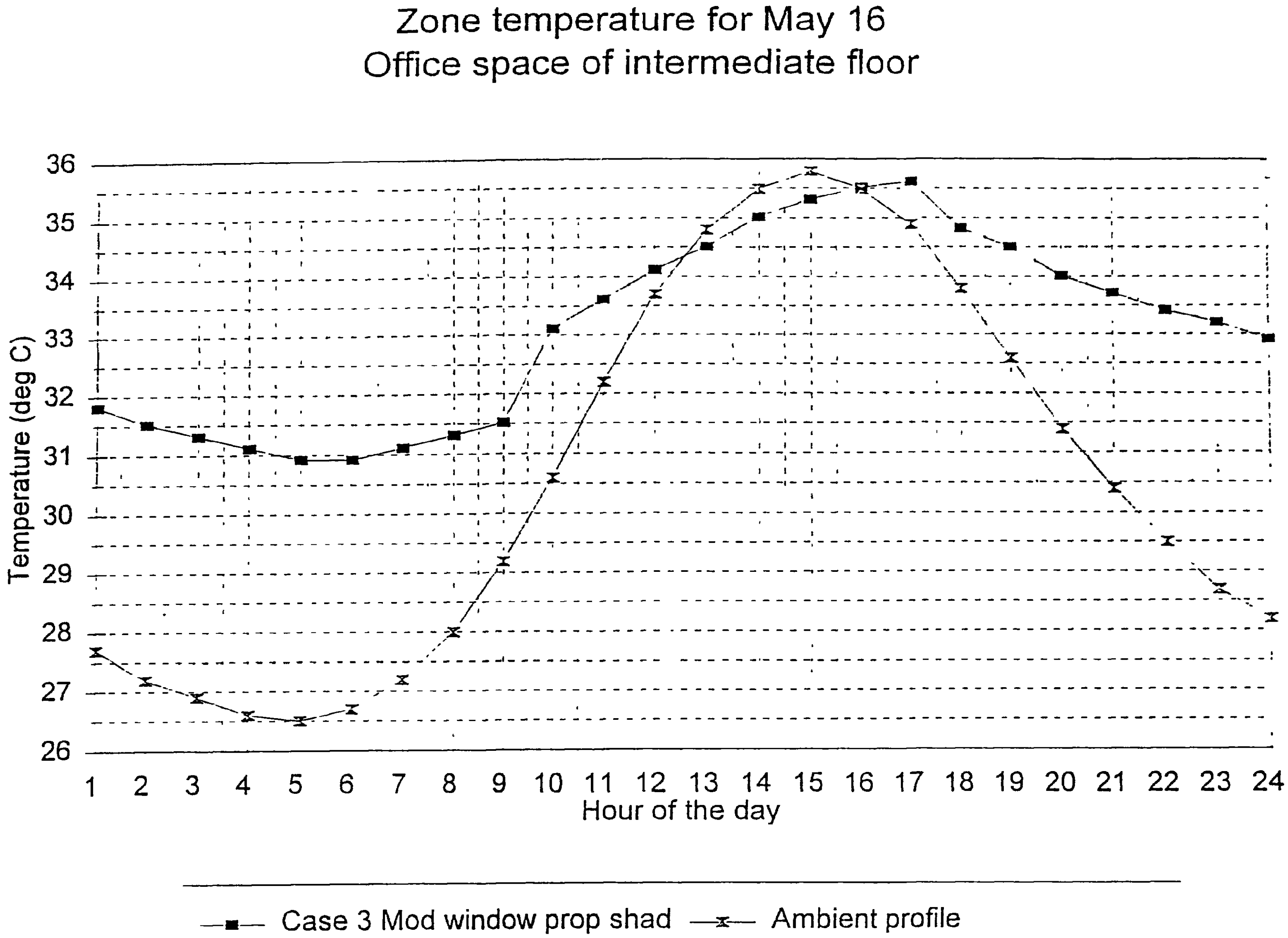

Zone temperature for May 16
Office space of intermediate floor
Temperature (deg C)
36
35
34
33
32
31
30
29
28
27
26
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of the day
Case 3 Mod window prop shad
Ambient profile

Fig 3.30

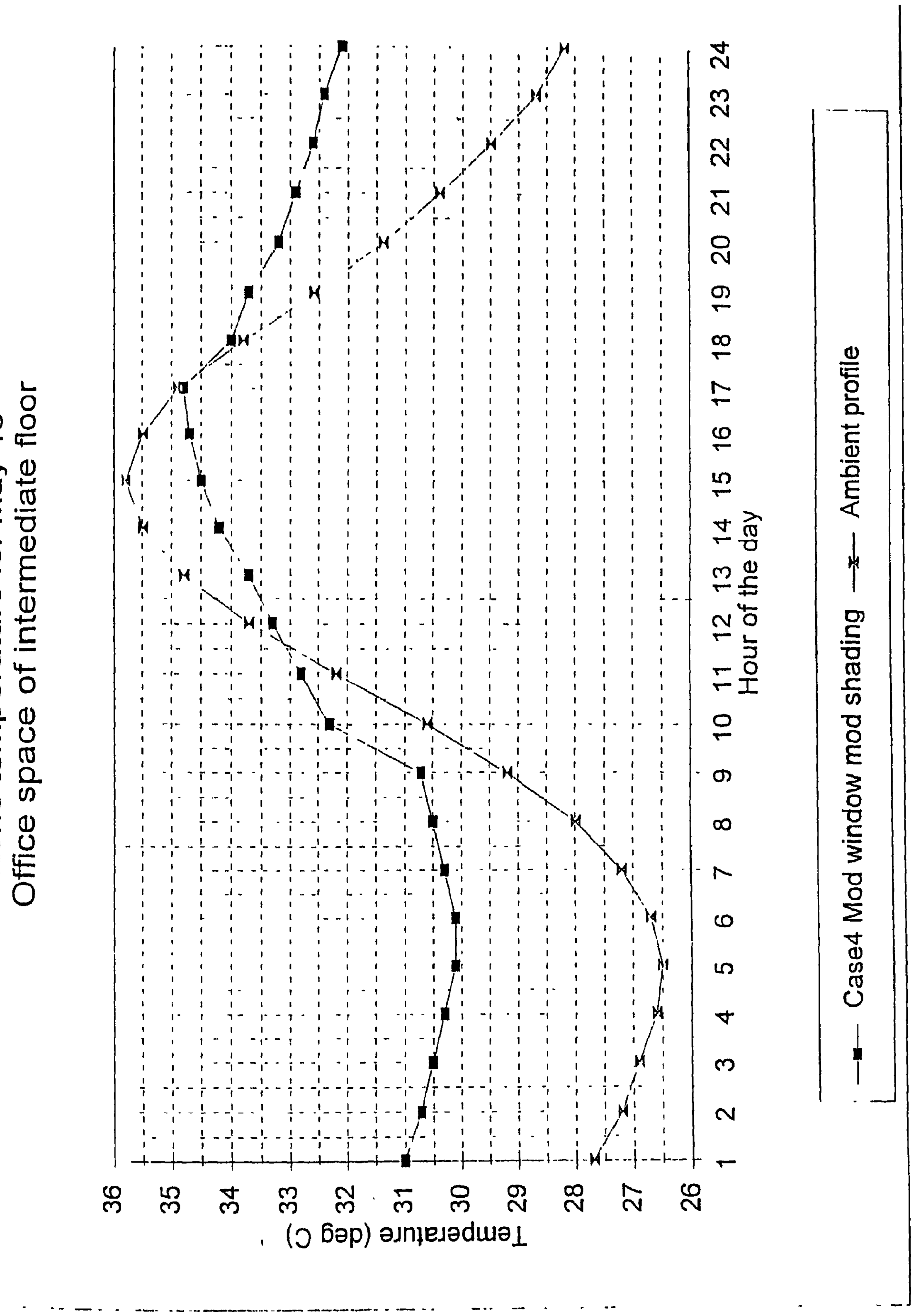

Zone temperature for May
Office space of intermediate floor
Temperature (deg C)
36
35
34
33
32
31
30
29
28
27
26
Hour of the day
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Case4 Mod window mod shading
Ambient profile

Fig 3.31

OFFICE SPACE

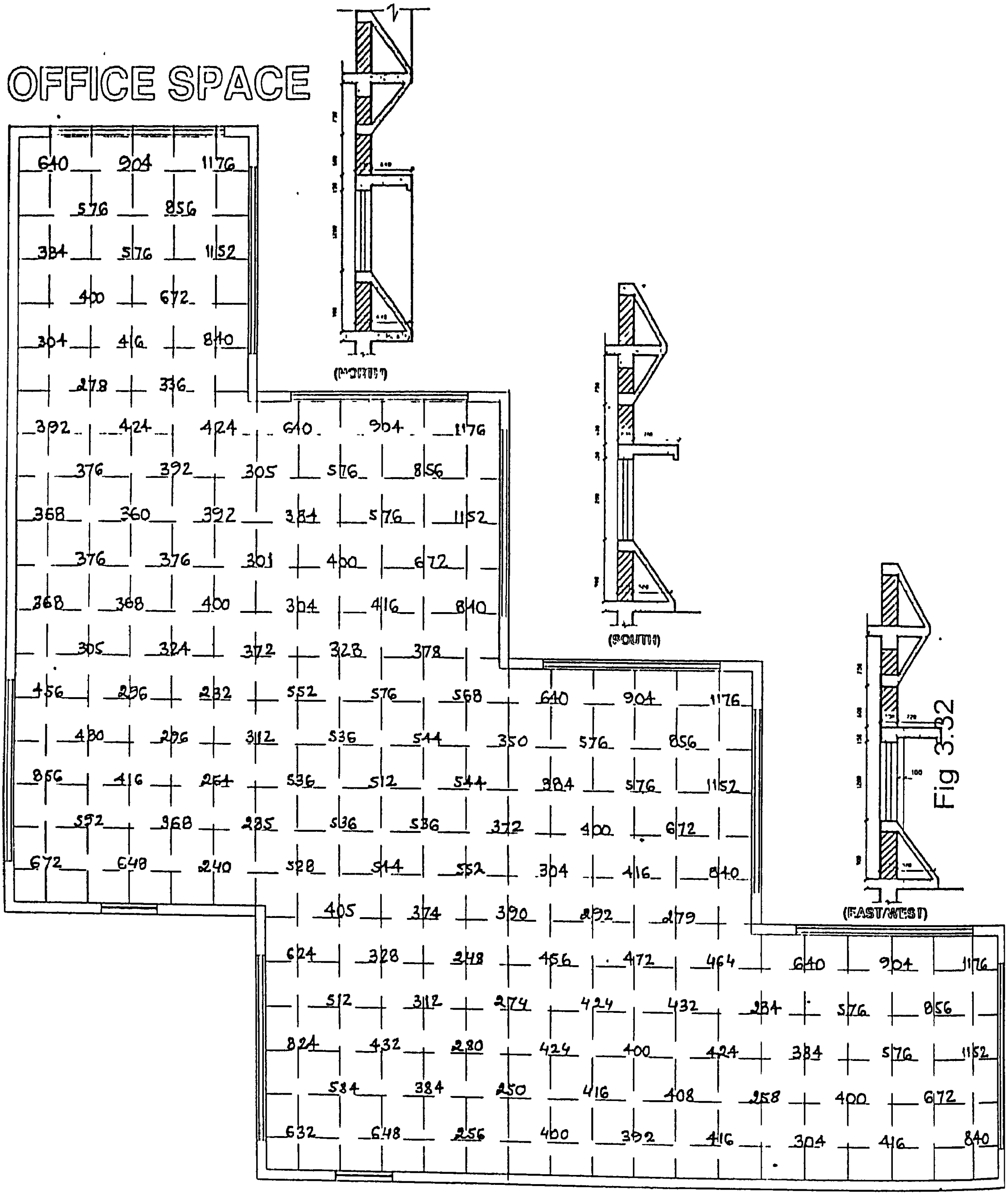
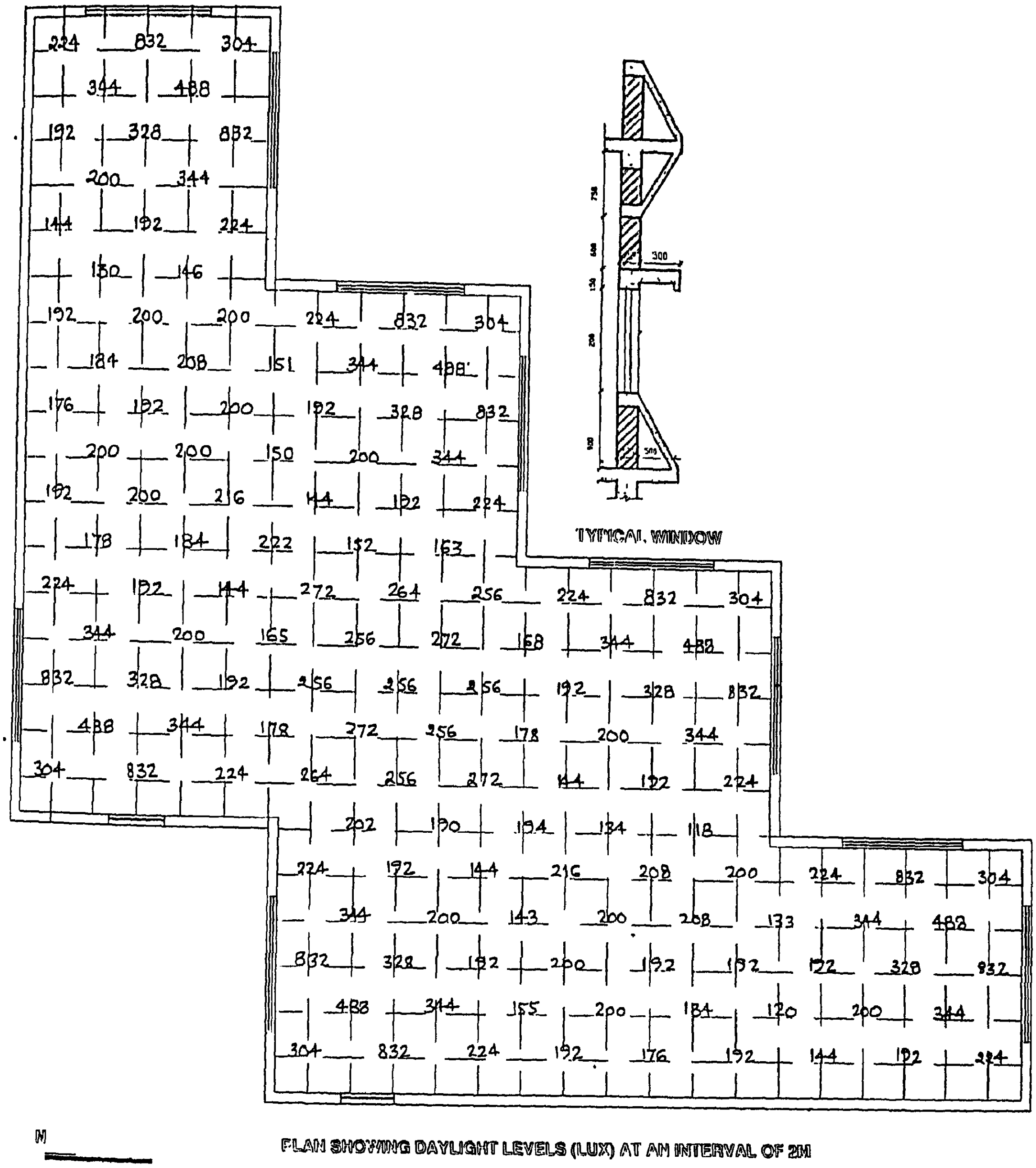


Fig 3.32

PLAN SHOWING DAYLIGHT LEVELS (LUX)AT AN INTERVAL OF 2M

CASE 4 MODIFIED WINDOW MODIFIED SHADIN

OFFICE SPACE



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF 2M

CASE 5 RECOMMENDED WINDOW PROPOSED SHADING

Fig 3.33

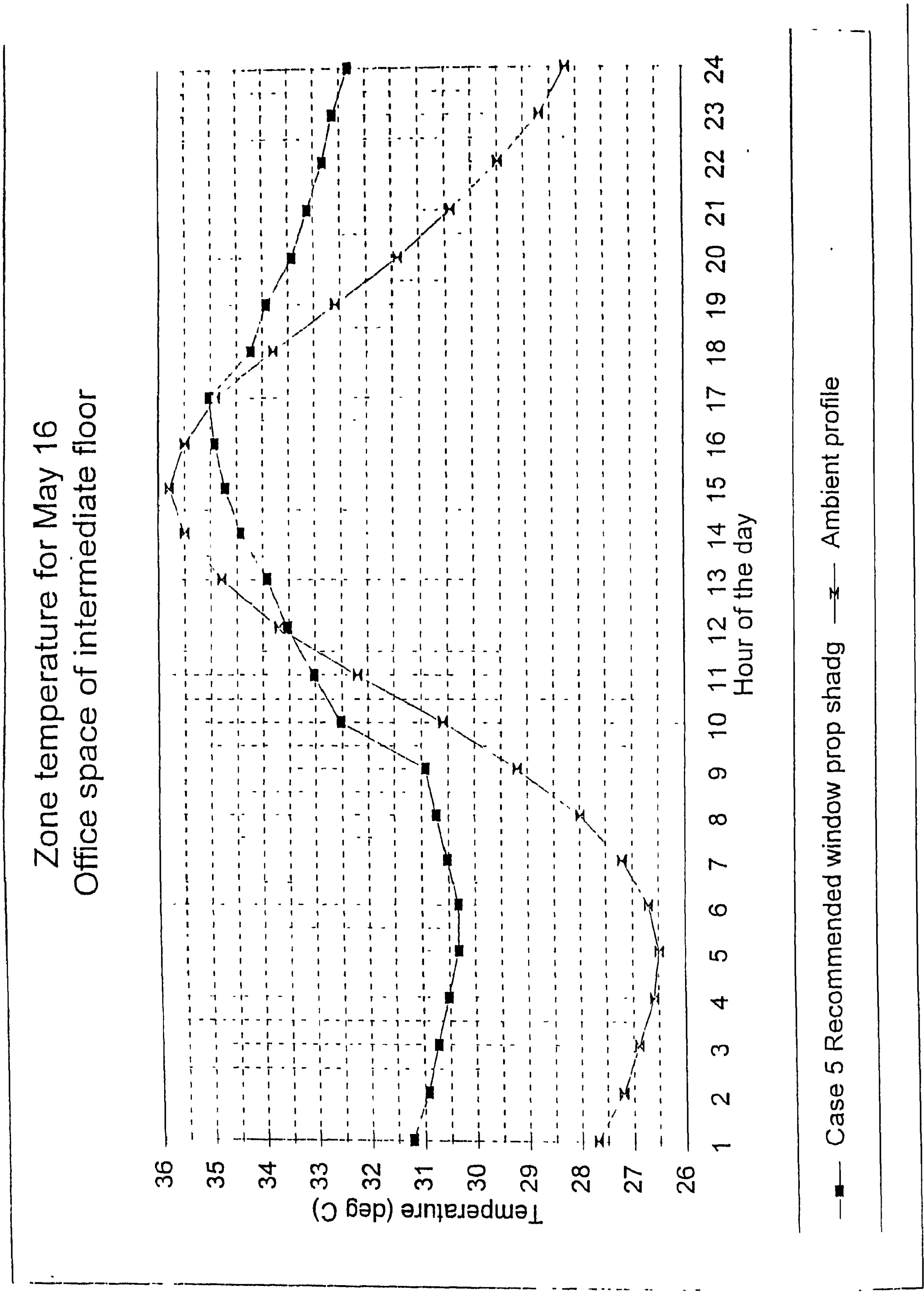
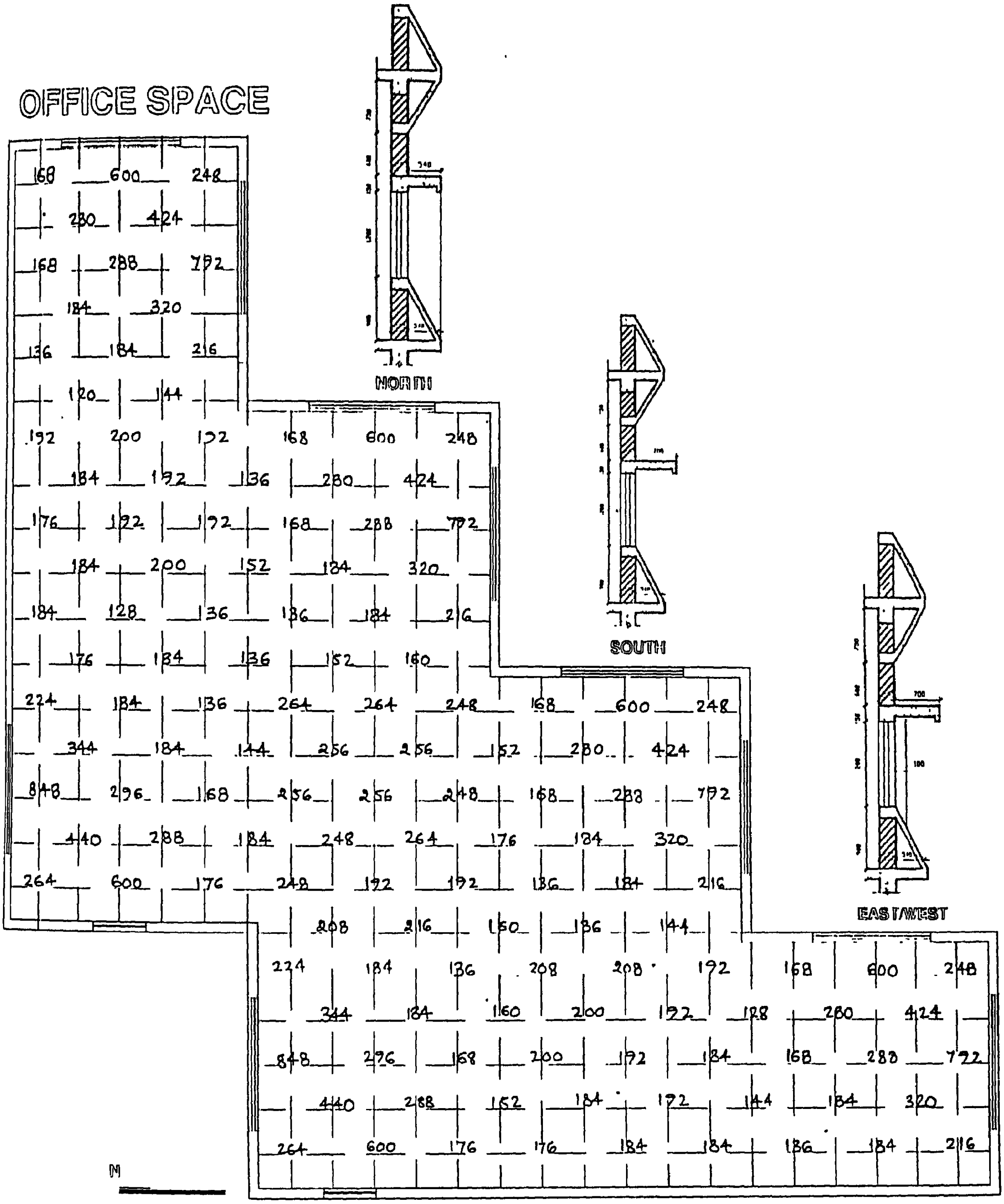

Zone temperature for May 16
Office space of intermediate floor
Temperature (deg C)
36
35
34
33
32
31
30
29
28
27
26
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of the day
Case 5 Recommended window prop shadg
Ambient profile

Fig 3.34



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF 2M

CASE 6 RECOMMENDED WINDOW RECOMMENDED SHADING

Fig 3.35

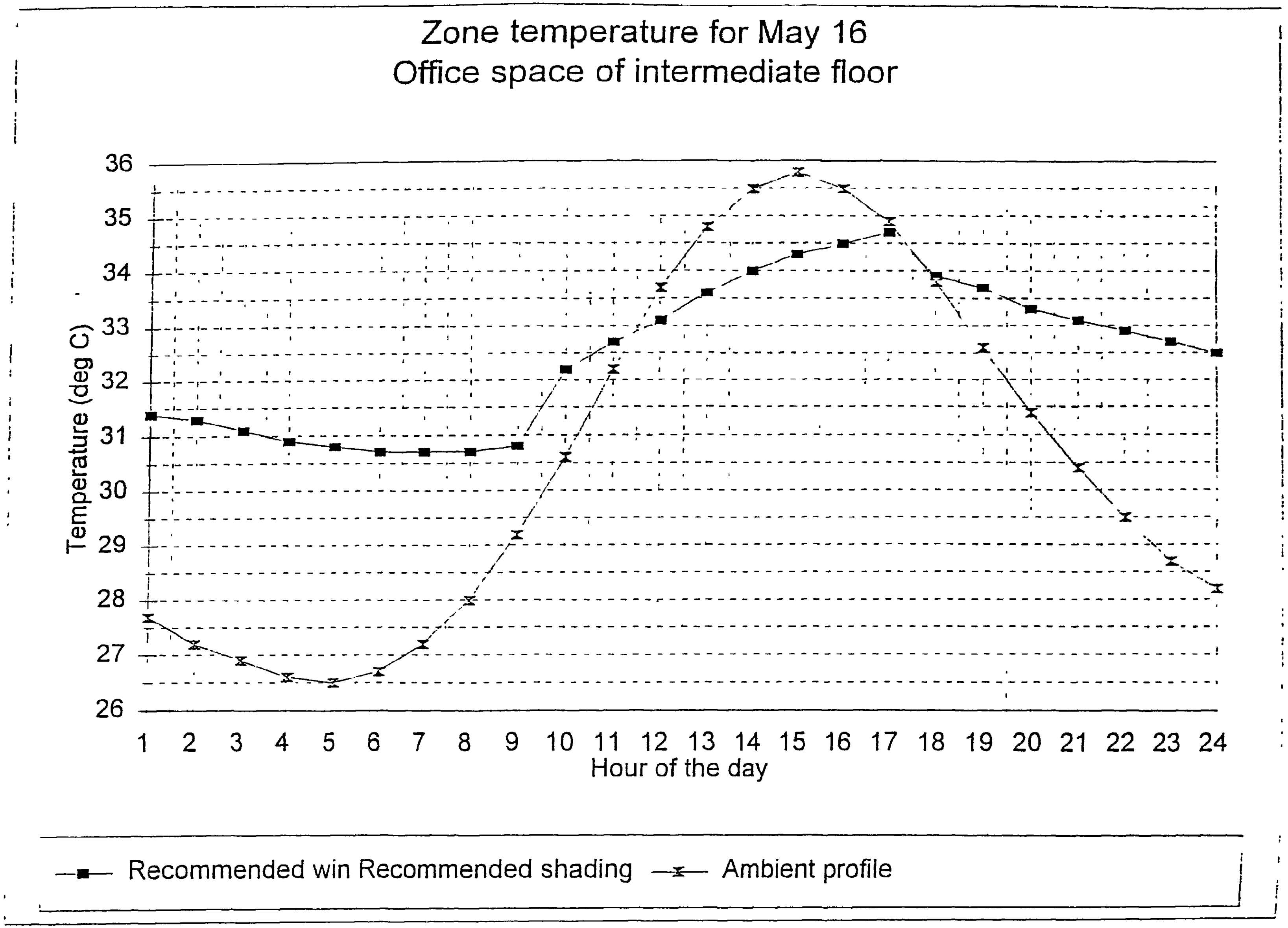
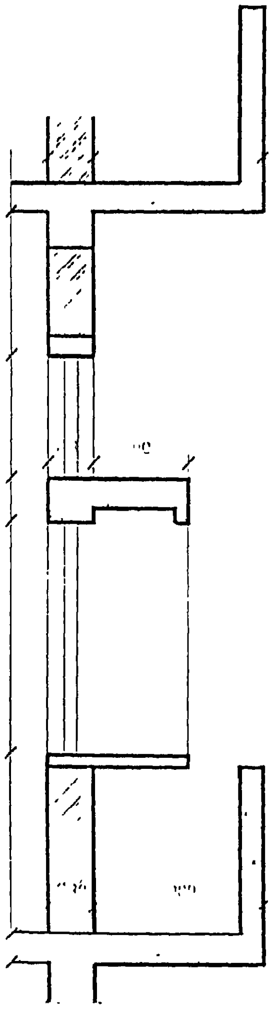
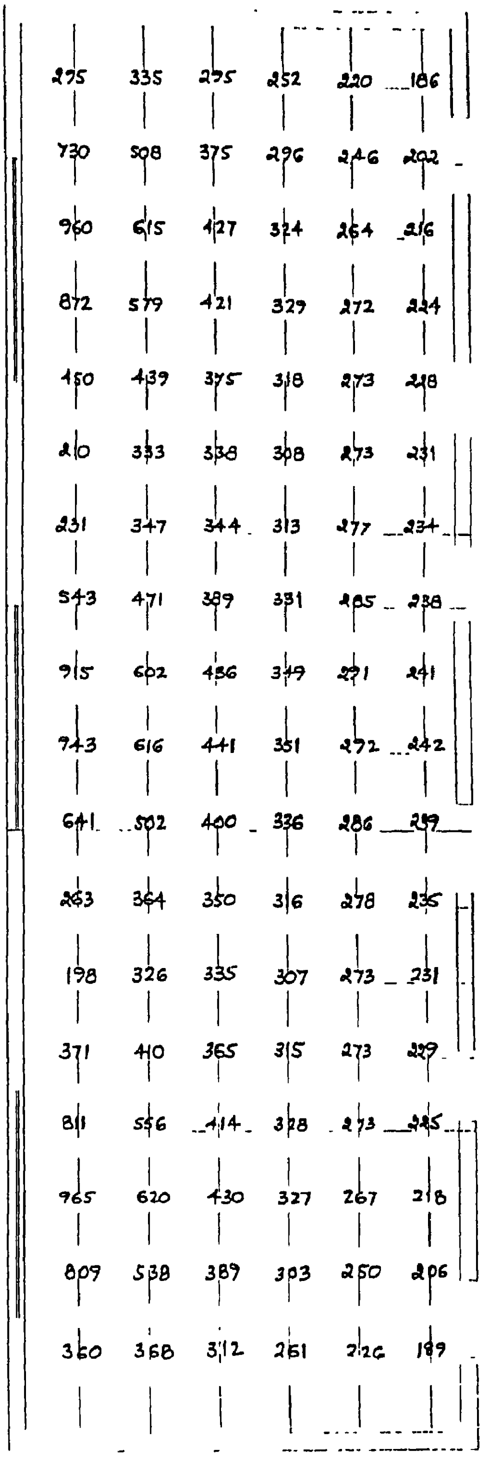

Zone temperature for May 16
Office space of intermediate floor
Temperature (deg C)
36
35
34
33
32
31
30
29
28
27
26
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of the day
Recommended win Recommended shading
Ambient profile

Fig 3.36

NORTH FACING LABORATORY



[illegible]



275	335	275	252	220	186
730	508	375	296	246	202
960	615	427	324	264	216
872	579	421	329	272	224
450	439	375	318	273	228
210	333	338	308	273	231
231	347	344	313	277	234
543	471	389	331	285	238
915	602	456	349	271	241
743	616	441	351	272	242
641	502	400	336	286	239
263	364	350	316	278	235
198	326	335	307	273	231
371	410	365	315	273	229
811	556	414	328	273	245
965	620	430	327	267	218
809	538	389	303	250	206
360	368	312	261	226	189

PLAN SHOWING DAYLIGHT LEVELS [illegible] AT AN INTERVAL OF [illegible]

FINAL DESIGN

Fig 3.37

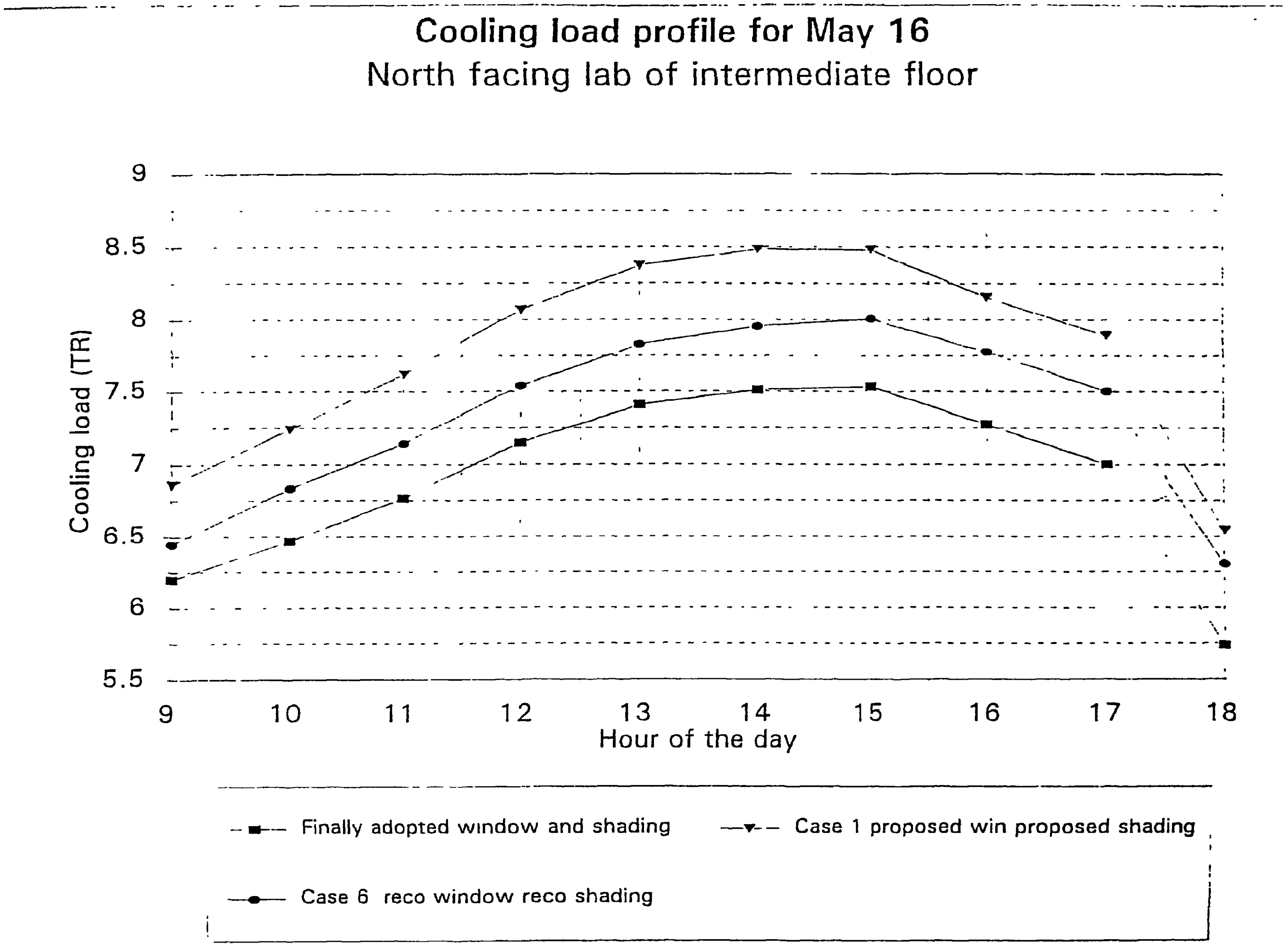
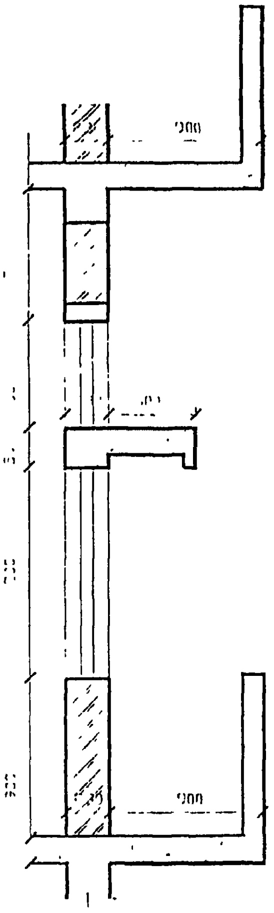
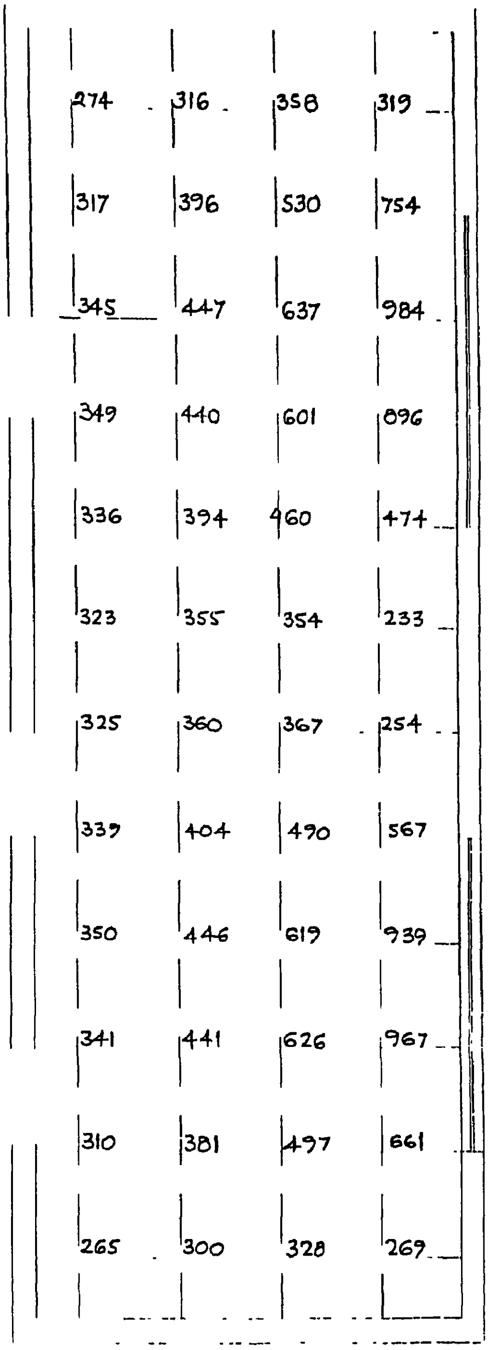

Cooling load profile for May 16
North facing lab of intermediate floor

Fig 3.38

SOUTH FACING LABORATORY



SECTION THROUGH WINDOW (enlarged)



274	316	358	319
317	396	530	754
345	447	637	984
349	440	601	896
336	394	460	474
323	355	354	233
325	360	367	254
339	404	490	567
350	446	619	939
341	441	626	967
310	381	497	661
265	300	328	269

PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF 1 M

FINAL DESIGN

Fig 3.39

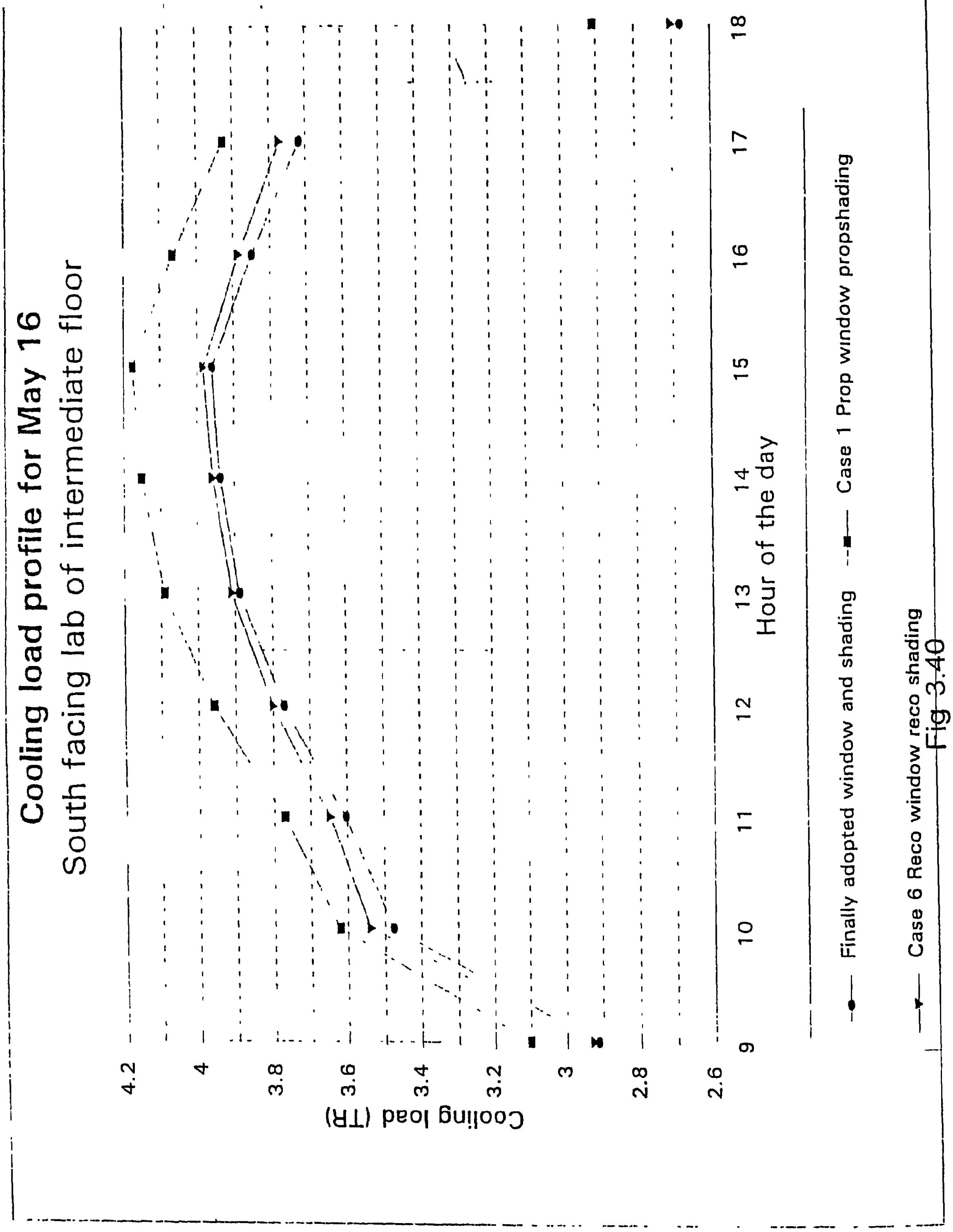
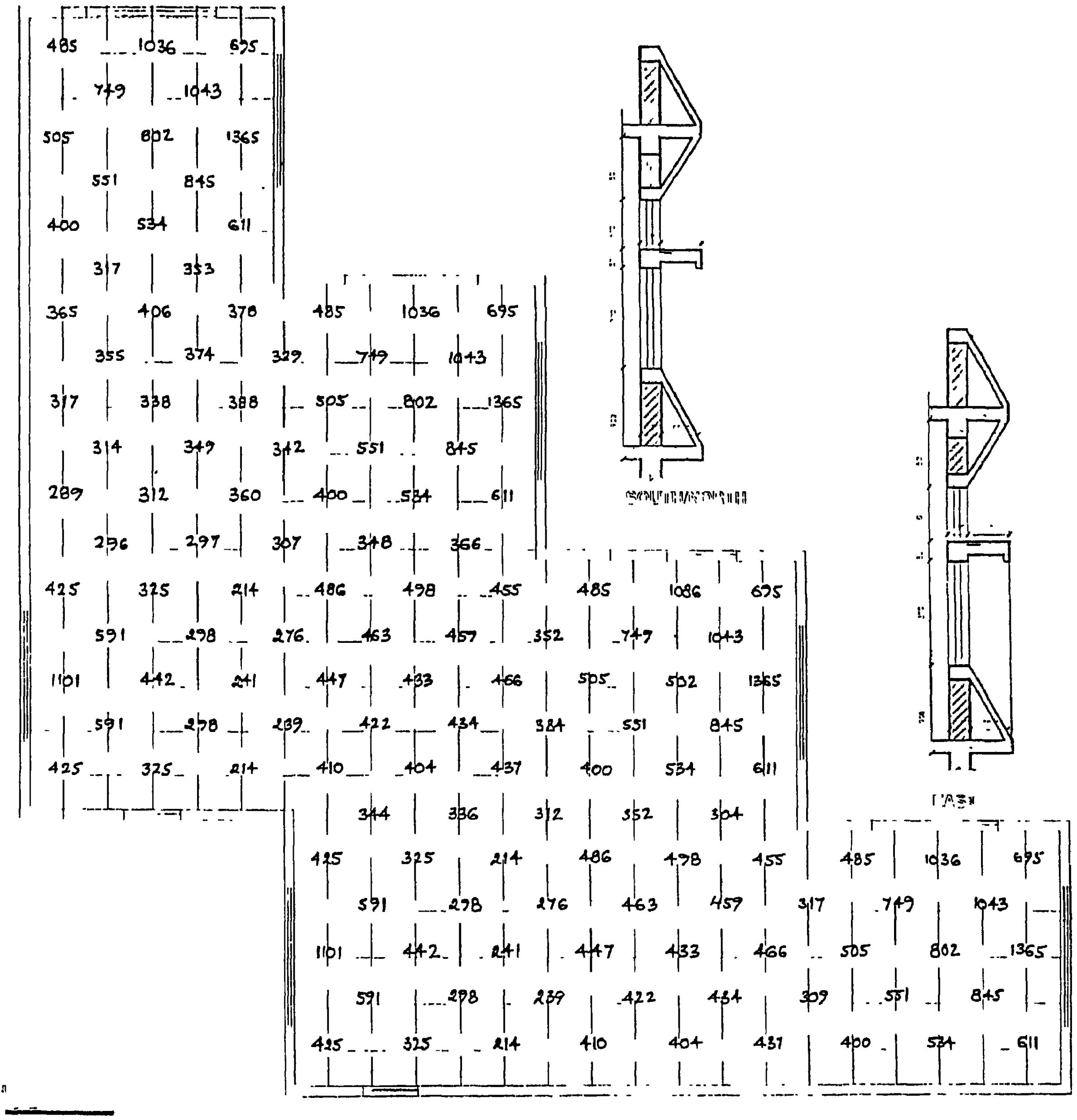


Fig 3.40

Pollution control board office building, Calcutta

OFFICE SPACE



PLAN SHOWING DAYLIGHT LEVELS (LUX) AT AN INTERVAL OF 2M

FINAL DESIGN

Fig 3.41

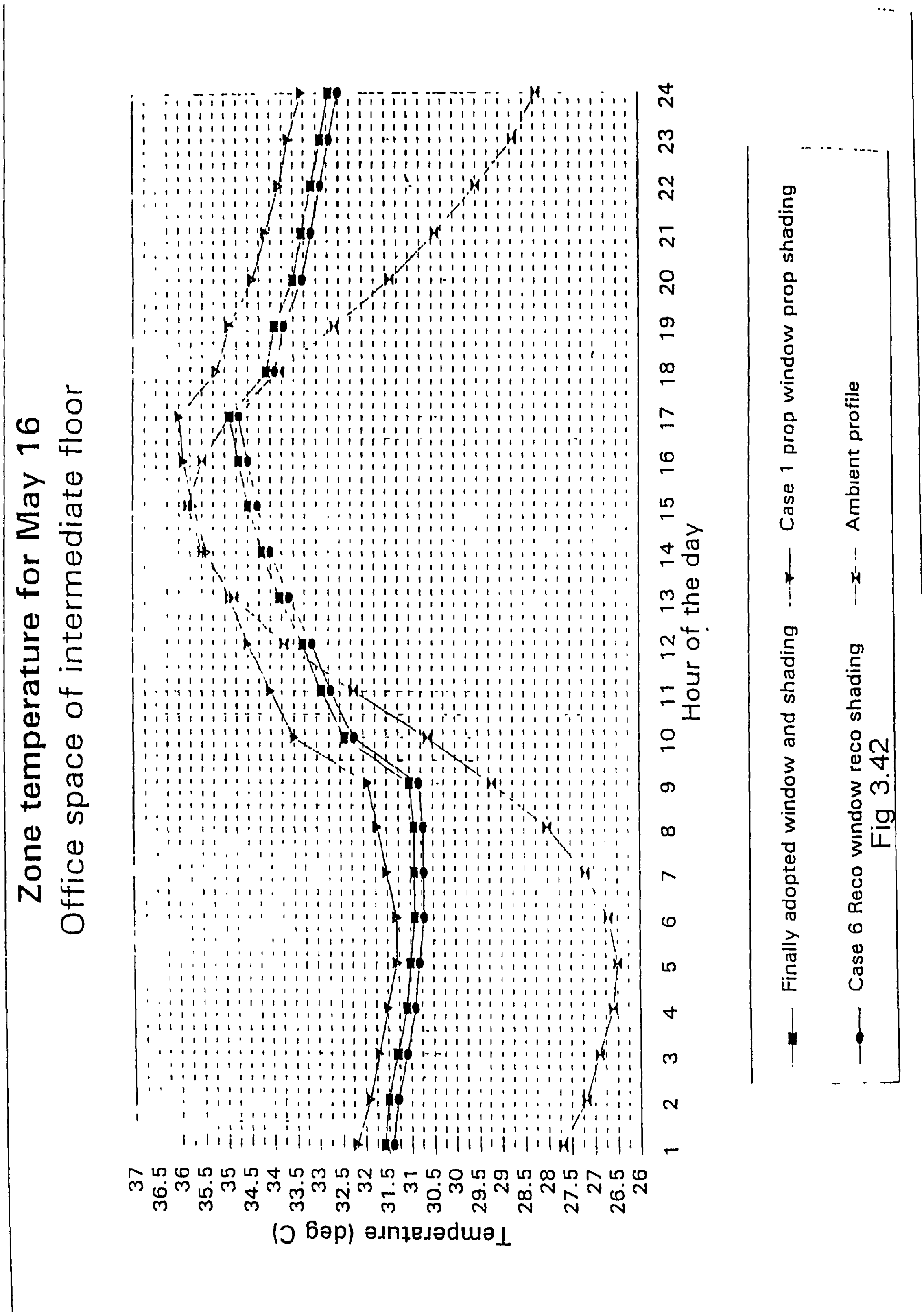
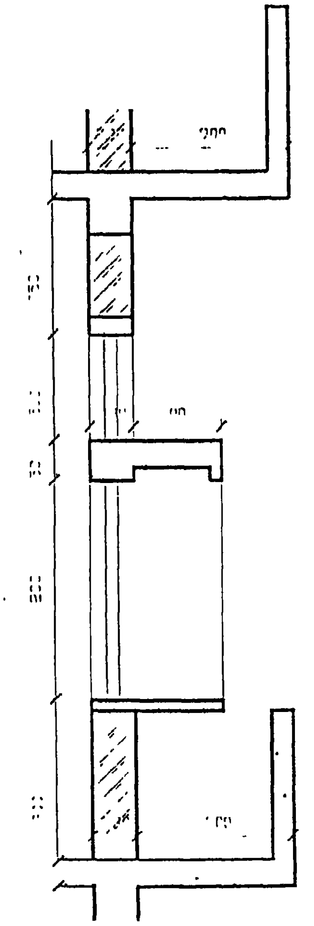
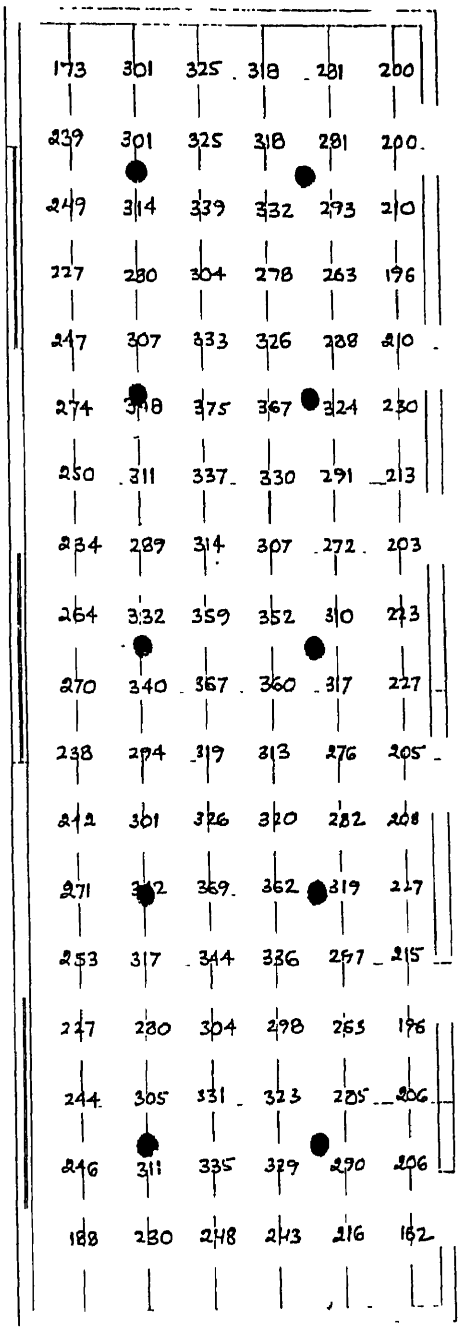

Zone temperature for May 16
Office space of intermediate floor
Temperature (deg C)
37
36.5
36
35.5
35
34.5
34
33.5
33
32.5
32
31.5
31
30.5
30
29.5
29
28.5
28
27.5
27
26.5
26
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Hour of the day
Finally adopted window and shading
Case 1 prop window prop shading
Case 6 Reco window reco shading
Ambient profile

Fig 3.42

NORTH FACING LABORATORY



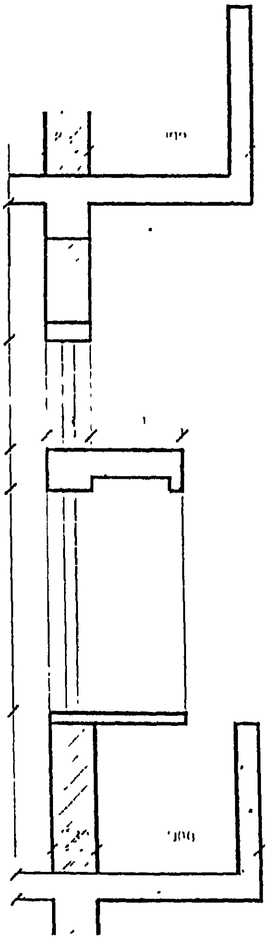


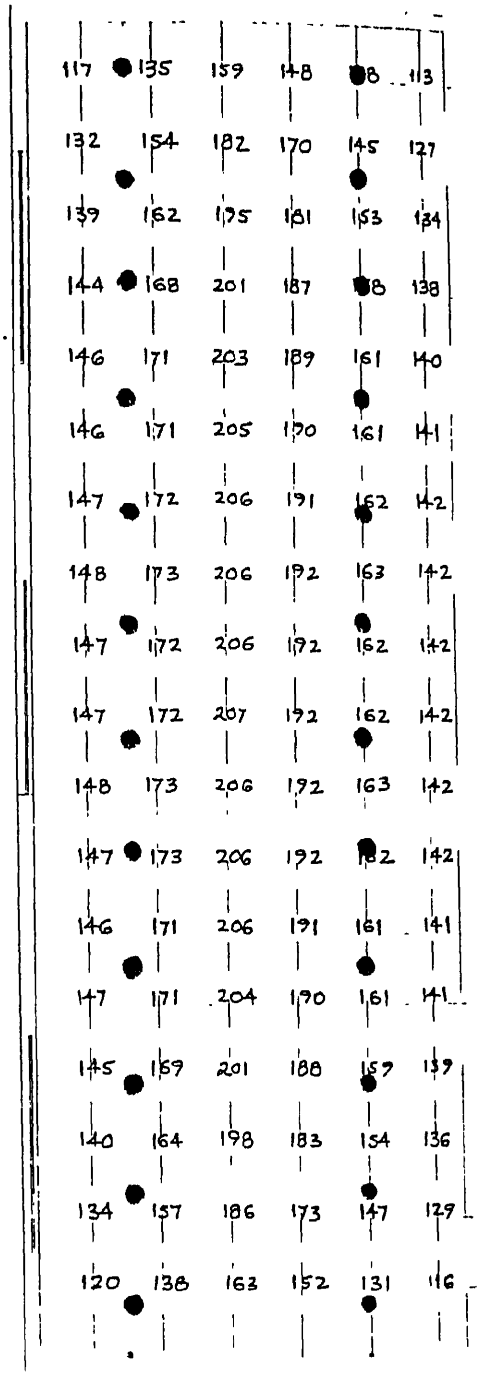
173	301	325	318	281	200
239	301	325	318	281	200
249	314	339	332	293	210
227	280	304	278	263	196
247	307	333	326	288	210
274	[illegible]	375	367	324	230
250	311	337	330	291	213
234	289	314	307	272	203
264	332	359	352	310	243
270	340	367	360	317	227
238	294	319	313	276	205
242	361	326	320	282	208
271	[illegible]	369	362	319	227
253	317	344	336	297	215
227	280	304	298	265	196
244	305	331	323	285	206
246	311	335	329	290	206
188	230	248	243	216	162

FINAL DESIGN

Fig 3.43

NORTH FACING LABORATORY



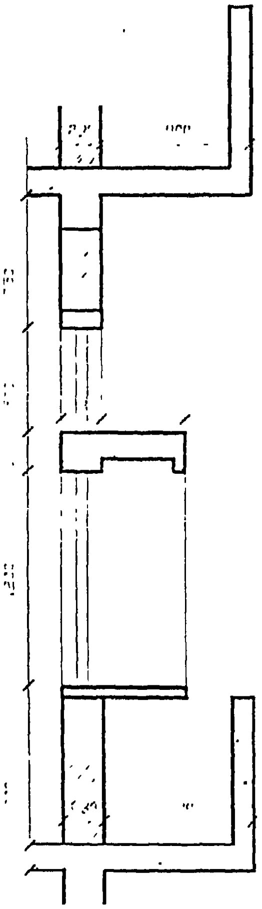


117	135	159	148	[illegible]8	113
132	154	182	170	145	127
139	162	175	181	153	134
144	168	201	187	[illegible]8	138
146	171	203	189	161	140
146	171	205	190	161	141
147	172	206	191	162	142
148	173	206	192	163	142
147	172	206	192	162	142
147	172	207	192	162	142
148	173	206	192	163	142
147	173	206	192	[illegible]2	142
146	171	206	191	161	141
147	171	204	190	161	141
145	169	201	188	157	139
140	164	198	183	154	136
134	157	186	173	147	129
120	138	163	152	131	116

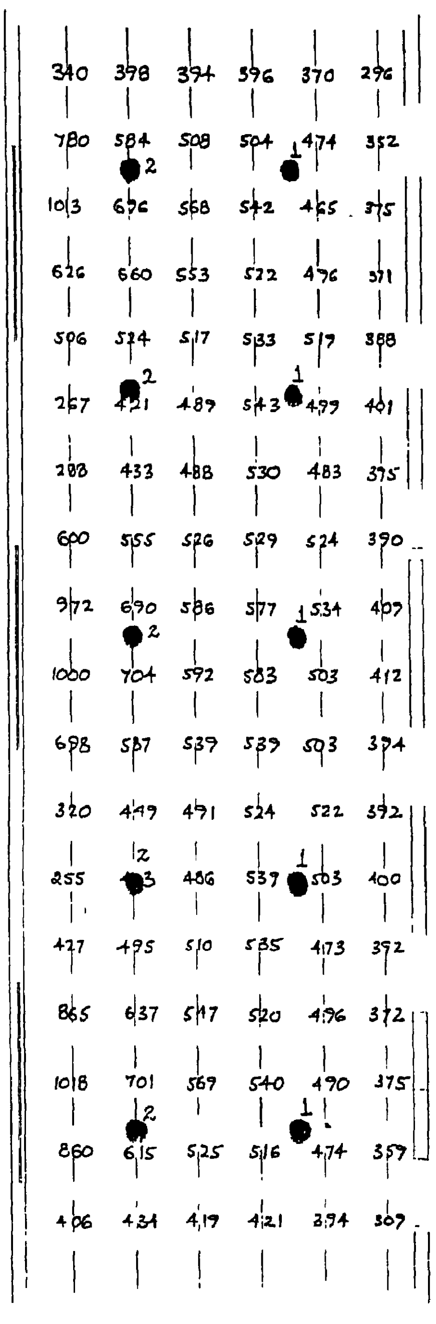
FINAL DESIGN

Fig 3.44

NORTH FACING LABORATORY



[illegible]



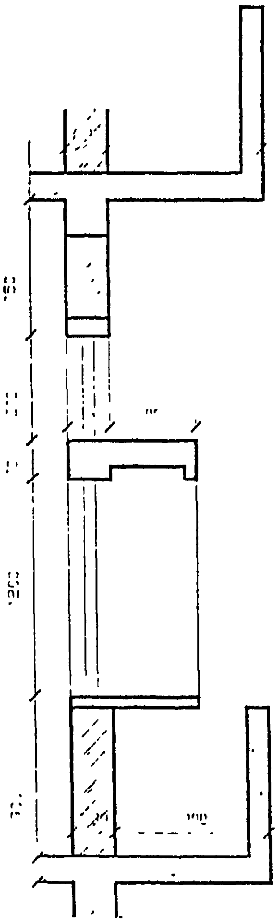
340	378	374	596	370	296
780	584	508	504	474	352
1013	676	568	542	465	375
626	660	553	522	476	371
506	524	517	533	517	388
267	421	489	543	499	401
283	433	488	530	483	375
600	555	526	529	524	390
972	690	586	577	534	407
1000	704	592	583	503	412
698	587	539	539	503	394
320	449	491	524	522	392
255	[illegible]	486	539	503	400
427	495	510	535	473	392
865	637	517	520	496	372
1018	701	569	540	490	375
860	615	525	516	474	359
406	434	419	421	394	307

[illegible]

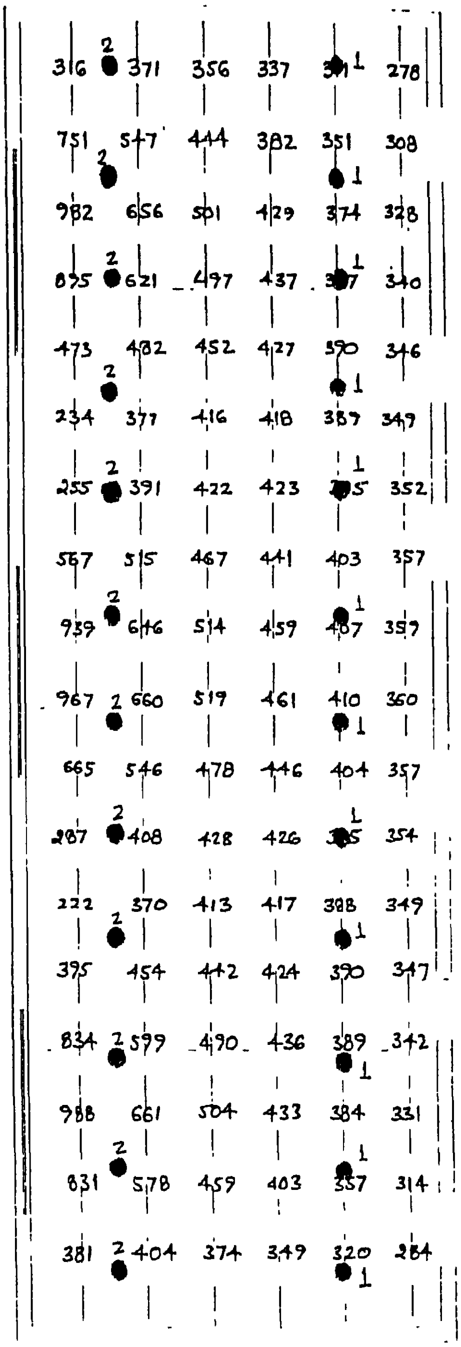
FINAL DESIGN

Fig 3.45

NORTH FACING LABORATORY



[illegible]

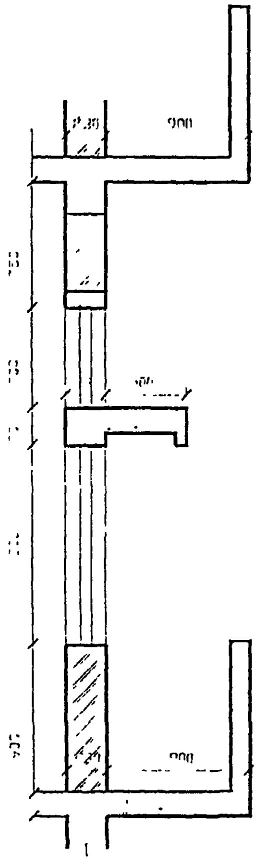


PLAN SHOWING [illegible]

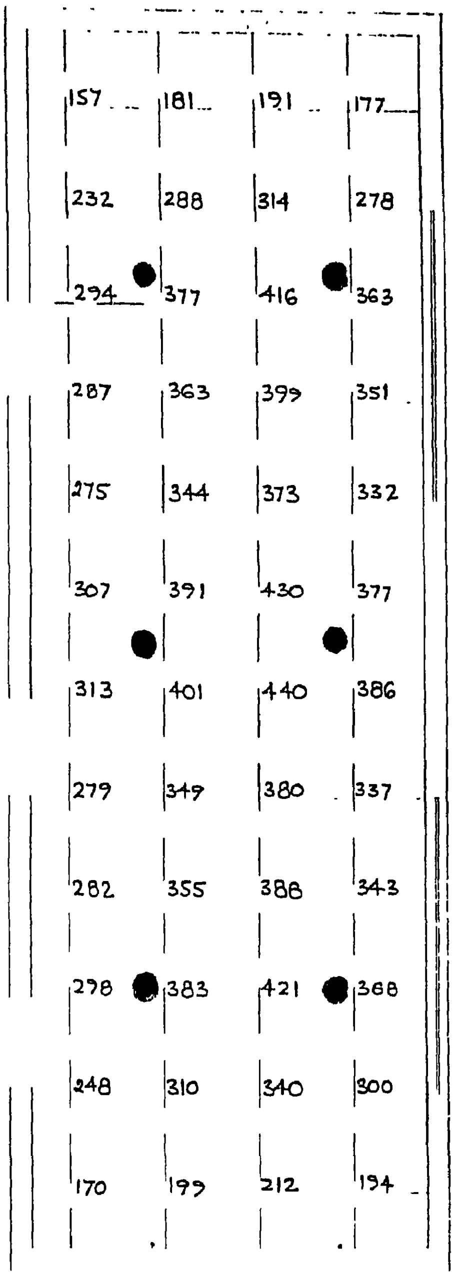
FINAL DESIGN

Fig 3.46

SOUTH FACING LABORATORY



SECTION OF [illegible] WINDOW (enlarged)



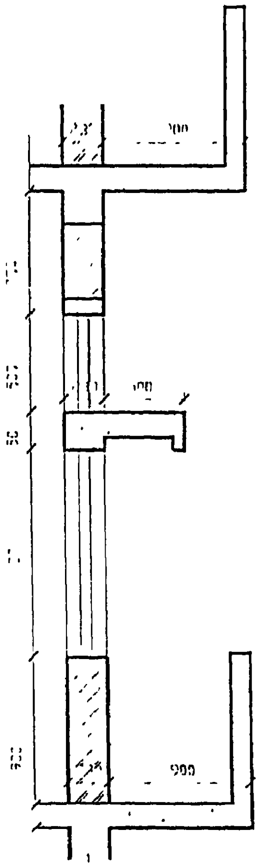
157	181	191	177
232	288	314	278
294	377	416	363
287	363	399	351
275	344	373	332
307	391	430	377
313	401	440	386
279	349	380	337
282	355	388	343
298	383	421	368
248	310	340	300
170	199	212	194

PLAN SHOWING [illegible] LEVELS (LUX) AT AN INTERVAL OF 1 M

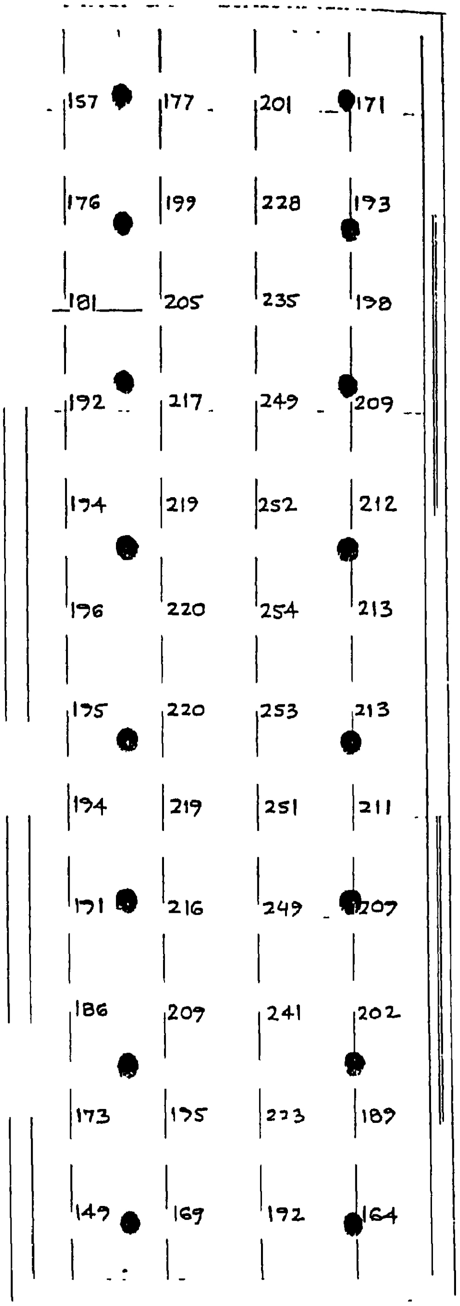
FINAL DESIGN

Fig 3.47

SOUTH FACING LABORATORY



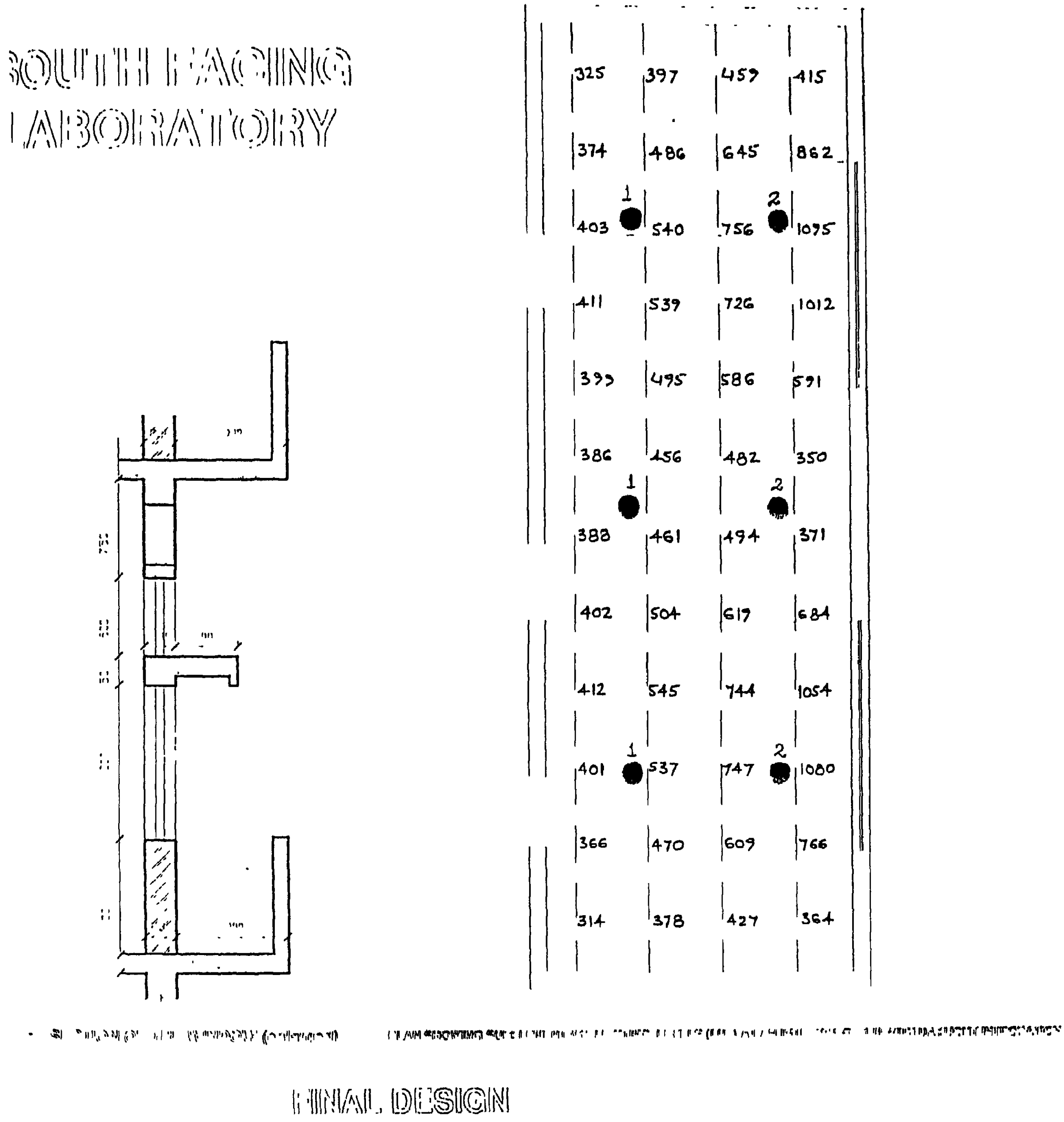
[illegible] WINDOW (enlarged)



[illegible]

FINAL DESIGN

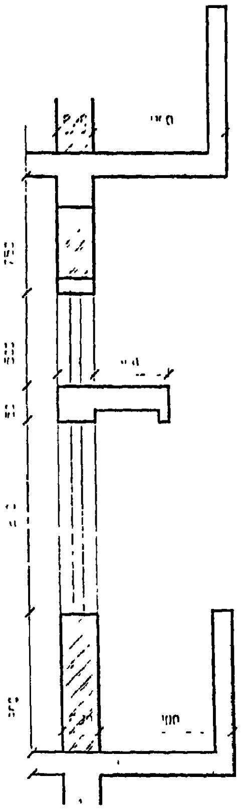
Fig 3.48



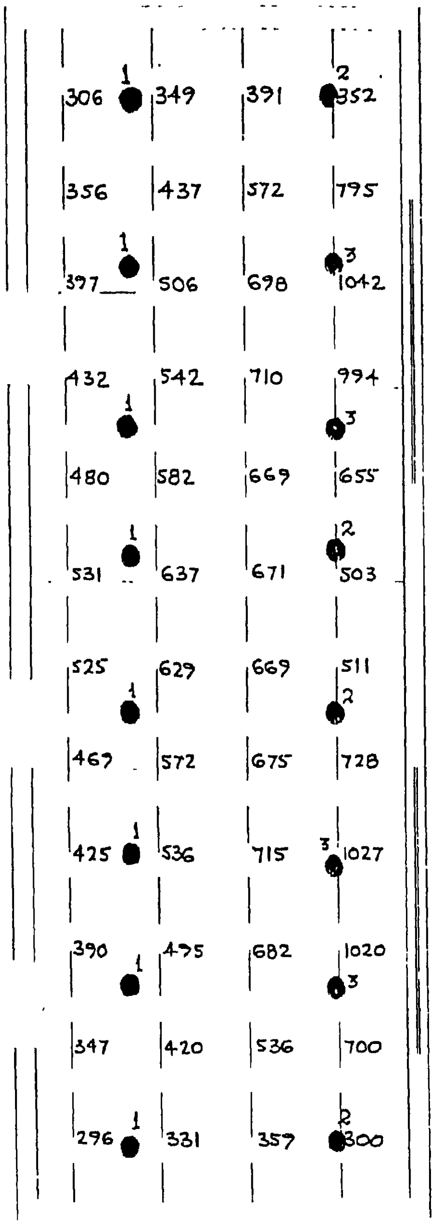
325	397	459	415
374	486	645	862
403	540	756	1075
411	539	726	1012
393	495	586	591
386	456	482	350
388	461	494	371
402	504	617	684
412	545	744	1054
401	537	747	1080
366	470	609	766
314	378	427	364

Fig 3.49

SOUTH FACING LABORATORY



SECTION OF THE WINDOW (enlarged)

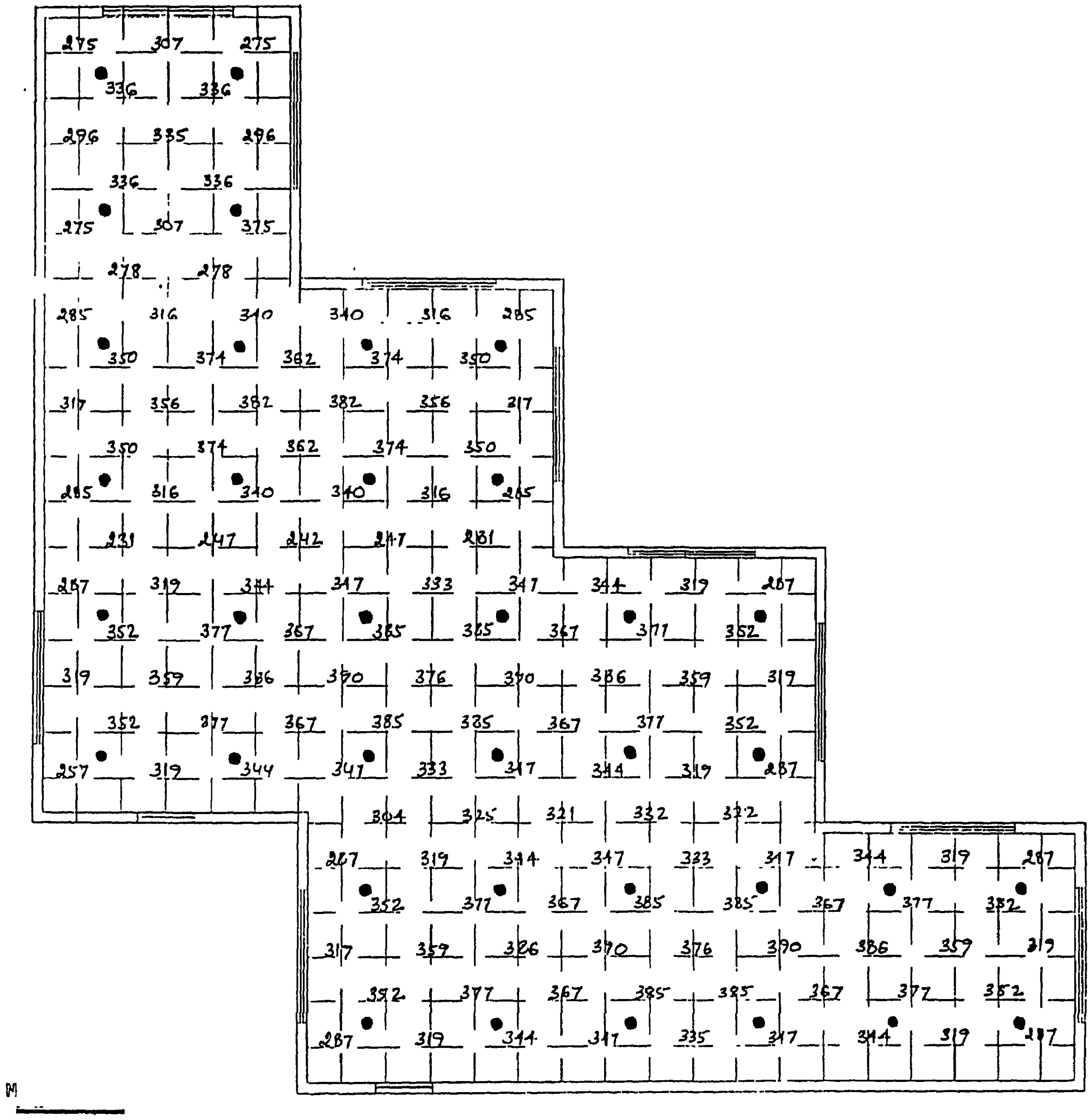


PLAN SHOWING SUPPLEMENTARY LIGHTING [illegible]

FINAL DESIGN

Fig 3.50

OFFICE SPACE

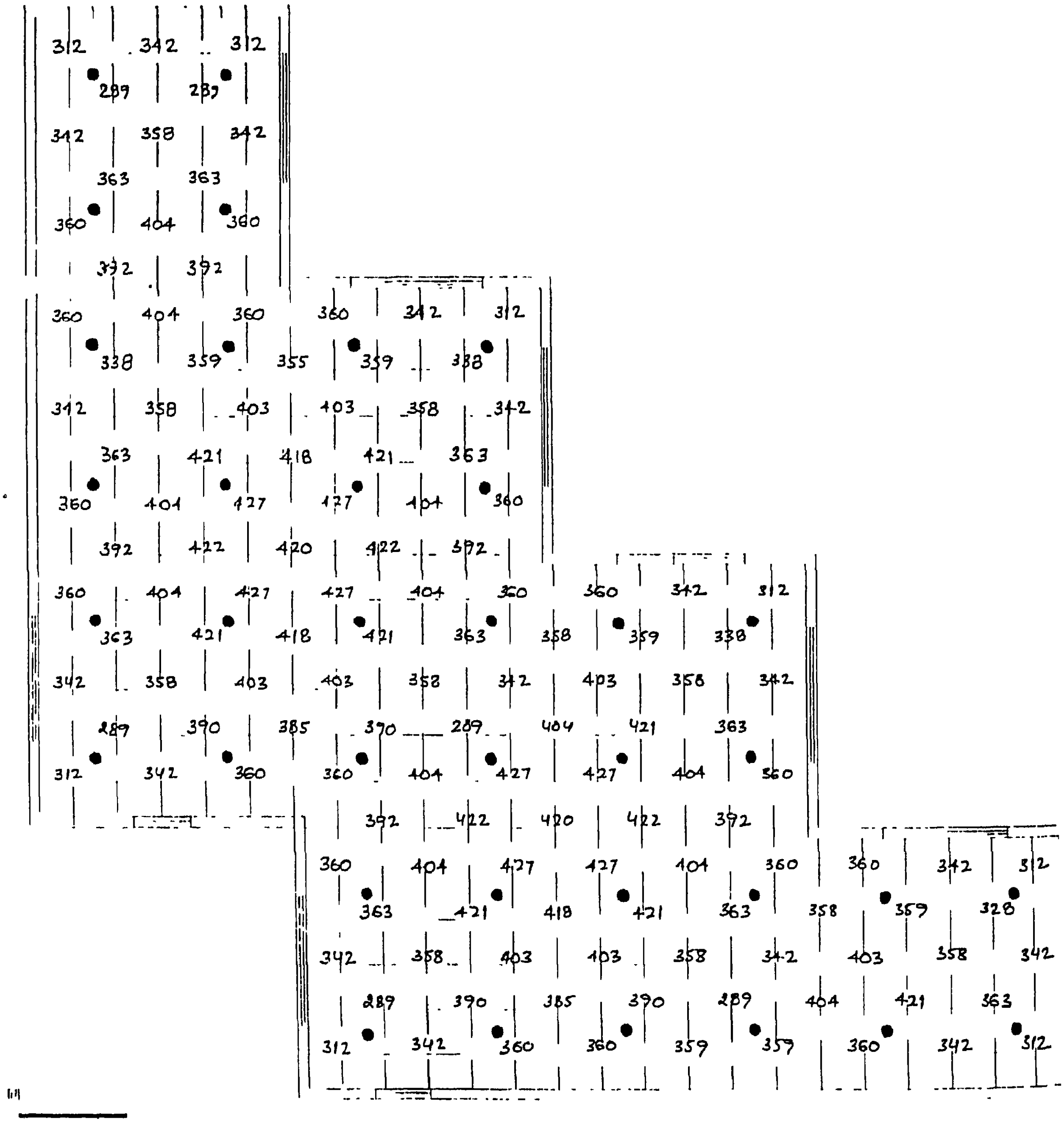


PLAN SHOWING ARTIFICIAL LIGHT LEVELS (LUX) AT AN INTERVAL OF 3M

FINAL DESIGN

Fig 3.51

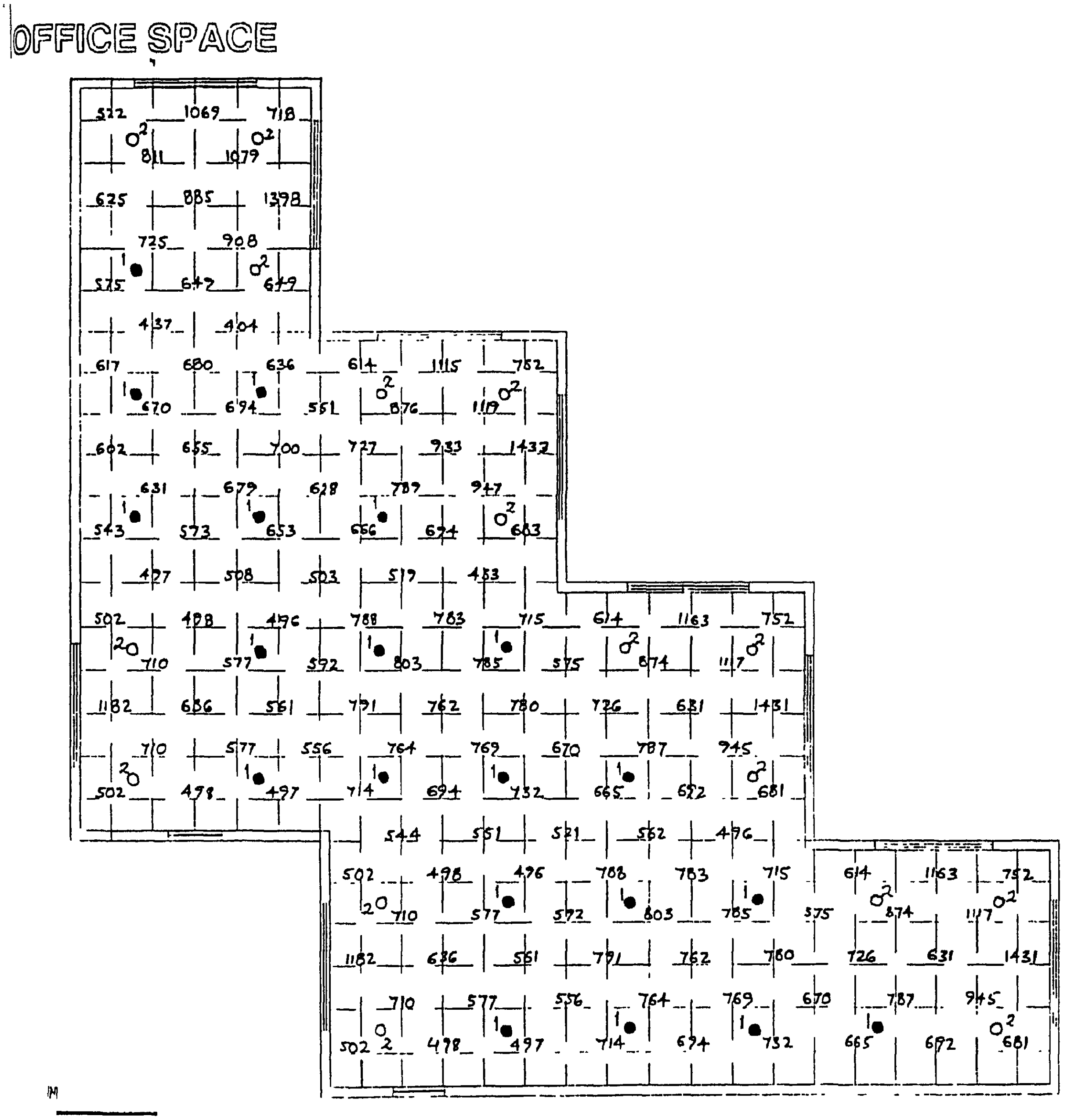
OFFICE SPACE



PLAN SHOWING ARTIFICIAL LIGHT LEVELS (LUX) AT [illegible]

FINAL DESIGN

Fig 3.52



PLAN SHOWING SUPPLEMENTARY LIGHT LEVELS (LUX) AT AN INTERVAL OF [illegible]

FINAL DESIGN

Fig 3.53

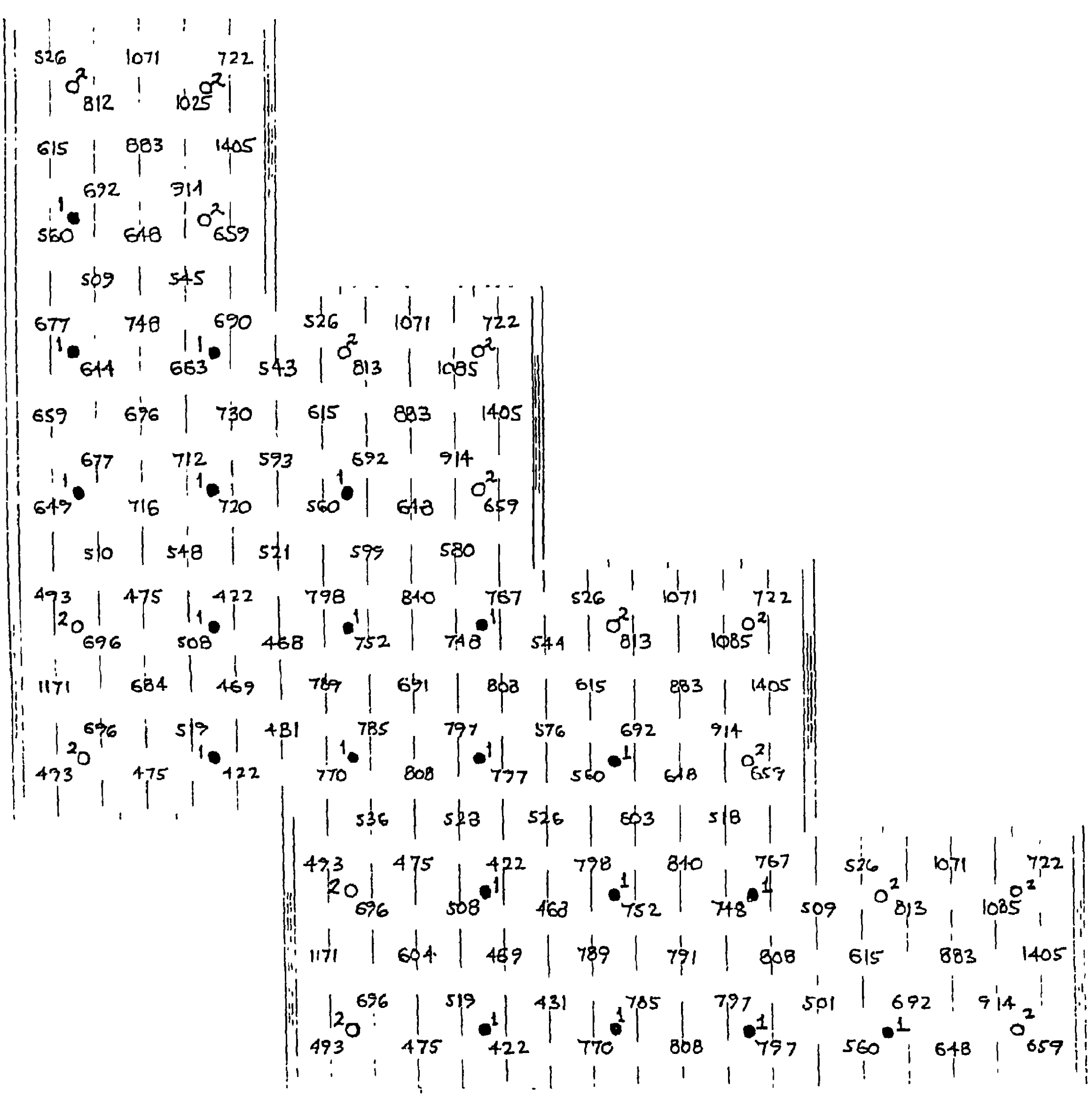

526 1071 722
812 1025
615 883 1405
692 914
560 648 659
509 545
677 748 690
644 663 543
659 696 730
677 712 593
647 716 720
510 548 521 599 580

Fig 3.54

Appendix 1

Sample input file for SUNCODE-PC

```
BUILDING DESCRIPTION FILE
RUNS
*    RUN LABEL     STATION    GROUND GROUND -START- -STOP-- SKYLINE  PAR.
*                   NAME       REFL.  TEMP. MON DAY MON DAY PROFILE  TYPE
*                             [FRAC]   [C]  [DATE]  [DATE]
*AAAAAAAAAAAAAAAA AAAAAAAAAA S.SSSS SSS.SS AAA XX. AAA XX. AAAAAA   AAAAAA
 SECONDFLOOR      CALCUTTA    0.200   27.0 JAN 01. JAN 20. <NONE>   <NONE>
ZONES
*   ZONE       HVAC      FLOOR  HGT  INFIL.  SOLAR  SOLAR INTERNAL  LATENT
*   NAME       TYPE      AREA         RATE  TO AIR  LOST    GAIN      GAIN
*                        [SM]   [M]  [AC/H] [FRAC] [FRAC]   [KW]      [KW]
*AAAAAAAAAA AAAAAAAAAA XXXXX.X XX.X SSS.SSS X.XXX  X.XXX SSSS.SSS SSSS.SSS
 OFFICE     <NONE>       324.   3.6   4.     0.10   0.05  IGAIN1    LGAIN1
WINDOWS
* INTERIOR   EXTERIOR   GLAZING     HEIGHT  LENGTH  ---LOCATION----
*   ZONE     SURFACE     TYPE                         HORZ.   VERT.
*                                     [M]      [M]     [M]      [M]
*AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA   XXXX.XX XXXX.XX XXXX.XX XXXX.XX
 OFFICE     SOUTHS     SINGLE          1.50    3.00    0.64    1.20
 OFFICE     SOUTHS     SINGLE          1.50    3.00    7.27    1.20
 OFFICE     SOUTHS     SINGLE          1.50    3.00   13.27    1.20
 OFFICE     SOUTHS     SINGLE          1.50    3.00   19.27    1.20
 OFFICE     NORTHS     SINGLE1         1.50    3.00    0.64    1.20
 OFFICE     NORTHS     SINGLE1         1.50    3.00    6.9     1.20
 OFFICE     EASTS      SINGLE2         1.50    3.00    0.64    1.20
 OFFICE     EASTS      SINGLE2         1.50    3.00    7.27    1.20
 OFFICE     EASTS      SINGLE2         1.50    3.00   13.27    1.20
 OFFICE     EASTS      SINGLE2         1.50    3.00   19.27    1.20
 OFFICE     WESTS      SINGLE3         1.50    1.50    2.25    1.20
 OFFICE     WESTS      SINGLE3         1.50    1.50    8.25    1.20
WALLS
*   WALL     --FRONT/INTERIOR SIDE--  --BACK/EXTERIOR SIDE---   WALL
*   TYPE       ZONE     SURF   SOLAR  ZONE OR    SURF   SOLAR   AREA
*              NAME     COEF   COEF.  SURFACE,   COEF   COEF.
*                       [W/C  [FRAC]  AMBIENT,   [W/C  [FRAC]   [SM]
*                       -SM]          GROUND     -SM]
*AAAAAAAAAA AAAAAAAAAA XX.XXX X.XXXX AAAAAAAAAA XX.XXX X.XXXX  XXXXX.X
 NORMAL     OFFICE      8.0   0.1    NORTHS     23.0   0.7        31.6
 NORMAL     OFFICE      8.0   0.1    SOUTHS     23.0   0.7        64.4
 NORMAL     OFFICE      8.0   0.1    EASTS      23.0   0.7        54.4
 NORMAL     OFFICE      8.0   0.1    WESTS      23.0   0.7        38.0
 CEILING    OFFICE      8.0   0.1    OFFICE      8.0   0.1       324.0
 FLOOR      OFFICE      8.0   0.1    OFFICE      8.0   0.15      324.0
 FRAME      OFFICE      8.0   0.0    NORTHS     23.0   0.7         2.6
 FRAME      OFFICE      8.0   0.0    SOUTHS     23.0   0.7         4.0
 FRAME      OFFICE      8.0   0.0    EASTS      23.0   0.7         4.0
 FRAME      OFFICE      8.0   0.0    WESTS      23.0   0.7         0.7
SURFACES
* EXTERIOR   COMPASS  TILT  HEIGHT  LENGTH  OVERHANG   LEFT       RIGHT
* SURFACE    AZIMUTH                          TYPE     SIDEFIN    SIDEFIN
*             [DEG]   [DEG]   [M]     [M]
*AAAAAAAAAA  XXX.X    XX.X XXXX.XX XXXX.XX AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA
 NORTHS        0.0    90.0    3.6    12.0  HORIZ      LEFT1      <NONE>
 SOUTHS      180.0    90.0    3.6    24.0  HORIZ      LEFT2      <NONE>
 EASTS        90.0    90.0    3.6    24.0  HORIZ      <NONE>     RIGHT1
```

```
 WESTS        270.0   90.0    3.6     12.0  <NONE>      <NONE>      RIGHT2
WALL.TYPES
*   WALL       LAYER      LAYER8     LAYER      LAYER      LAYER      LAYER
*   TYPE        # 1        # 2        # 3        # 4        # 5        # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 NORMAL     CEMPLAS1  BRICK     CEMPLAS2  <NONE>    <NONE>    <NONE>
 FRAME      ALUMINIUM <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING    CEMPLAS   RCC       FLFIN     <NONE>    <NONE>    <NONE>
 FLOOR      FLFIN     RCC       CEMPLAS   <NONE>    <NONE>    <NONE>
MASS.TYPES
*MASS TYPE    CONDUCTIVITY   DENSITY    SPECIFIC HEAT   THICKNESS   NODES
*               [W/M-C]      [KG/CM]     [KJ/KG-C]        [M]
*AAAAAAAAAA     X.XXXX      XXXX.XXX      X.XXXX        XX.XXXX     XX.
 CEMPLAS        0.721       1762.0        0.84           0.006       1.
 CEMPLAS1       0.721       1762.0        0.84           0.0190      1.
 CEMPLAS2       0.721       1762.0        0.84           0.0180      1.
 BRICK          0.811       1820.0        0.88           0.225       2.
 FLFIN          0.719       1648.0        0.88           0.0250      1.
 RCC            1.58        2288.0        0.88           0.1         1.
 ALUMINIUM      9.999       2800.0        0.89           0.006       1.
GLAZING.TYPES
* GLAZING     GLAZING   SHADING EXTINCTION  INDEX OF  THICKNESS  NUMBER
*  TYPE       U VALUE    COEF.     COEF.   REFRACTION OF LAYER     OF
*             [W/SM-C]   [FRAC]   [1/MM]     [NONE]     [MM]     LAYERS
*AAAAAAAAAA   SS.SSSSS  SS.SS8SS  X.XXXX     X.XXXX    X.XXXX      XX.
 SINGLE        5.67      0.20     0.0197     1.5260    5.5          1.
 SINGLE1       5.67      0.14     0.0197     1.5260    5.5          1.
 SINGLE2       5.67      0.14     0.0197     1.5260    5.5          1.
 SINGLE3       5.67      0.5      0.0197     1.5260    5.5          1.
OVERHANG.TYPES
* OVERHANG    VERTICAL  HORIZONTAL
*   TYPE       OFFSET   PROJECTION
*               [M]        [M]
*AAAAAAAAAA    XX.XX      XX.XX
 HORIZ          1.10       0.62
SIDEFIN.TYPES
* SIDEFIN      OFFSET   LENGTH OF
*  TYPE        TO SIDE  PROJECTION
*               [M]       [M]
*AAAAAAAAAA    XX.XX     XX.XX
 LEFT1          0.00      6.00
 LEFT2          0.00      6.00
 RIGHT1         0.00      6.00
 RIGHT2         0.00      6.00
OUTPUTS
* OUTPUT    TIME    UNITS    OUTPUT   BUILDING   OUTPUT    FORMAT?
*  TYPE    PERIOD            SEASON   ELEMENT    SECTION
*         [H/D/M]  [E/M]                                    [Y/N]
*AAAAAAAA    A        A     AAAAAAAA    XXXX.      XXXX.      A
 ZONES       H        M     YEAR        <ALL>        6.       Y
SCHEDULES
*SCHEDULE  SEASON  HR   VALUE    HR   VALUE    HR   VALUE    HR   VALUE
*AAAAAAAA AAAAAAAA XX. XXXX.XXX  XX. XXXX.XXX  XX. XXXX.XXX  XX. XXXX.XXX
 IGAIN1   YEARW    10.   11.5    18.    2.8    20.   0.00
 LGAIN1   YEARW    10.   14.25   18.    3.5    20.   0.00
SEASONS
* SEASON     START DATE    STOP DATE    DAY OF WEEK
*  NAME        MON DAY      MON DAY    [ALL/M-F/S-S]
```

```
*AAAAAAAA      AAA XX.       AAA XX.         AAA
 YEAR          JAN 11.       JAN 11.         ALL
 YEARW         JAN 01.       DEC 31.         M-F
STATIONS
* STATION     LAT. LONG.  ELEV.  FILENAME  DATA  UNITS  -START-  -STOP--
*  NAME      [DEG] [DEG]  [M]              TYPE  [E/M]  MON DAY  MON DAY
*AAAAAAAAAA XX.XX XXX.X XXXXX. AAAAAAAAAA  XX.     A    AAA XX.  AAA XX.
 CALCUTTA   22.53  88.3     6. CALCUT.WET  4.      M    JAN 01.  DEC 31.
END OF FILE
```

APPENDIX: Standard output file for Daylight Program

```
------------------------------------------------------------
Room-id : WBPCB lab South Facing
------------------------------------------------------------
Input details


Room ht. is  3.60
Working plane height is   .90
Grid spacing  1.00

Effective opening area (corr. due to grills)  .840
Maintenance factor for glass  .800
Design sky  8000

Average reflection coefficient of wall AB is .500
Average reflection coefficient of wall BC is .500
Average reflection coefficient of wall CD is .500
Average reflection coefficient of wall DA is .500


Side dist. of AB is  12.80
Side dist. of BC is   4.20
Side dist. of CD is  12.80
Side dist. of DA is   4.20


No. of windows in side AB is  2
No.   dist.   width    ht.    cill    rc    S Ht.   projec.   drop
 1    1.70    3.00    1.20    .90    .15    .00     .65     .00
 2    3.40    3.00    1.20    .90    .15    .00     .65     .00


No. of windows in side BC is  0
No. of windows in side CD is  0
No. of windows in side DA is  0


No. of ventilators in side AB is  2
No.   dist.   width    ht.    cill    rc    S Ht.   projec.   drop
 1    1.70    3.00    .50    2.25    .15    .75    1.05     .00
 2    3.40    3.00    .50    2.25    .15    .75    1.05     .00
No. of ventilators in side BC is  0
No. of ventilators in side CD is  0
No. of ventilators in side DA is  0



Horizontal plane

    Pt.         SC      ERC      IRC     TOTAL     lux
xcord..  ycord.
 1.00    1.00   2.2011   .0000   1.4773   3.6784    294
 2.00    1.00   2.6547   .0000   1.4848   4.1394    331
 3.00    1.00   2.2651   .0000   1.4848   3.7498    299
 4.00    1.00   1.8159   .0000   1.4848   3.3007    264
 1.00    2.00   7.4490   .0000   1.4773   8.9263    714
 2.00    2.00   4.6203   .0000   1.4848   6.1050    488
```

3.00	2.00	3.1925	.0000	1.4848	4.6773	374
4.00	2.00	2.3185	.0000	1.4848	3.8033	304
1.00	3.00	10.1562	.0000	1.4773	11.6335	930
2.00	3.00	5.8166	.0000	1.4848	7.3014	584
3.00	3.00	3.7620	.0000	1.4848	5.2467	419
4.00	3.00	2.6422	.0000	1.4848	4.1270	330
1.00	4.00	9.2566	.0000	1.4773	10.7339	858
2.00	4.00	5.3939	.0000	1.4848	6.8786	550
3.00	4.00	3.6815	.0000	1.4848	5.1662	413
4.00	4.00	2.6861	.0000	1.4848	4.1708	333
1.00	5.00	4.5743	.0000	1.4773	6.0516	484
2.00	5.00	3.7734	.0000	1.4848	5.2581	420
3.00	5.00	3.1317	.0000	1.4848	4.6165	369
4.00	5.00	2.5310	.0000	1.4848	4.0158	321
1.00	6.00	2.0903	.0000	1.4773	3.5676	285
2.00	6.00	2.5536	.0000	1.4848	4.0384	323
3.00	6.00	2.6778	.0000	1.4848	4.1626	333
4.00	6.00	2.3841	.0000	1.4848	3.8688	309
1.00	7.00	2.6801	.0000	1.4773	4.1574	332
2.00	7.00	2.6987	.0000	1.4848	4.1835	334
3.00	7.00	2.7350	.0000	1.4848	4.2197	337
4.00	7.00	2.4031	.0000	1.4848	3.8879	311
1.00	8.00	6.6998	.0000	1.4773	8.1771	654
2.00	8.00	4.1219	.0000	1.4848	5.6067	448
3.00	8.00	3.2535	.0000	1.4848	4.7382	379
4.00	8.00	2.5685	.0000	1.4848	4.0533	324
1.00	9.00	11.4357	.0000	1.4773	12.9130	1033
2.00	9.00	5.6086	.0000	1.4848	7.0933	567
3.00	9.00	3.7493	.0000	1.4848	5.2340	418
4.00	9.00	2.6985	.0000	1.4848	4.1833	334
1.00	10.00	12.0887	.0000	1.4773	13.5660	1085
2.00	10.00	5.6957	.0000	1.4848	7.1804	574
3.00	10.00	3.6943	.0000	1.4848	5.1790	414
4.00	10.00	2.5990	.0000	1.4848	4.0838	326
1.00	11.00	8.6040	.0000	1.4773	10.0813	806
2.00	11.00	4.2372	.0000	1.4848	5.7219	457
3.00	11.00	3.0224	.0000	1.4848	4.5072	360
4.00	11.00	2.2267	.0000	1.4848	3.7115	296
1.00	12.00	3.8624	.0000	1.4773	5.3397	427
2.00	12.00	2.3094	.0000	1.4848	3.7942	303
3.00	12.00	2.0772	.0000	1.4848	3.5620	284
4.00	12.00	1.7099	.0000	1.4848	3.1946	255

```
 @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@                             @@@@@@@@@@@@@@@@@
@@@@@@@                                                 @@@@@@@
@@@@     *   *  *   *  ****   ****   *****  *      *       @@@@
@@       *   *  *   *  *   *  *   *  *      *      *         @@
@        *****  *   *  ****   ****   ****   *      *          @
@@       *   *  *   *  *   *  *   *  *      *      *         @@
@@@@     *   *   ***   ****   ****   *****  *****  *****   @@@@
@@@@@@@                                                 @@@@@@@
@@@@@@@@@@@@@@@@@                             @@@@@@@@@@@@@@@@@
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TERI
BUILDING ENERGY GROUP                 Phone:   (011) 4622246
HABITAT PLACE                         FAX:     (011) 4623609
LODI ROAD
NEW DELHI 110 003



   "SPECWRITER"  INTERIOR LIGHTING POINT-BY-POINT CALCULATIONS
   ------------------------------------------------------------
   Version: 3.0HLI



                          03/06/97

   FOR:

                    Line 1 of description
                    Line 2 of description
                    Line 3 of description
                    Line 4 of description
                    Line 5 of description
```

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```
DINATES ARE METERS.                                     ICS--
                                                         PTS.
MINANCE IS HORIZONTAL LUX.                              286.0
                                              MAXIMUM   429.5
COORDINATE =     0.9                          MINIMUM   100.8
     ( * = LOCATION OF SINGLE LUMINAIRE )     AVG/MIN     2.84
                                              MAX/MIN     4.26
                                              MEAN DEV   66.60

  \ X |        1.0       3.0
Y  \  |    0.0       2.0       4.0
----------+----+----+----+----+--
       |
 12.0 +  158. 193. 211. 198. 169.
       |
       |
 11.0 +  227. 298. 338. 308. 246.
       |
       |
 10.0 +  270.   *  415.   *  293.
       |      363.      377.
       |
  9.0 +  253. 331. 374. 343. 273.
       |
       |
  8.0 +  244. 315. 353. 326. 262.
       |
       |
  7.0 +  277. 368. 419. 382. 300.
       |
       |        *         *
  6.0 +  282. 377. 430. 391. 306.
       |
       |
  5.0 +  248. 322. 362. 333. 267.
       |
       |
  4.0 +  247. 321. 362. 332. 266.
       |
       |
  3.0 +  269. 361. 412. 375. 292.
       |        *         *
       |
  2.0 +  240. 318. 362. 329. 260.
       |
       |
  1.0 +  171. 212. 233. 218. 182.
       |
       |
  0.0 +  101. 133. 141. 136. 118.
       |
----------+----+----+----+----+--
```

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```
        ECHO OF INPUT FILE:  I.IN
                             ----


                         Line 1 of description
                         Line 2 of description
                         Line 3 of description
                         Line 4 of description
                         Line 5 of description


     ROOM DIMENSIONS    REFLECTANCES
        X =   4.20        0.500  WEST WALL
        Y =  12.80        0.500  NORTH WALL
        Z =   3.60        0.500  EAST WALL
                          0.500  SOUTH WALL
                          0.100  FLOOR
                          0.700  CEILING

     TOTAL LUMINAIRES:      6
     TOTAL KW LOAD:     0.450   WATTS/SQUARE METER:  8.37


-----------------------------------------------------------------
 for photometric file  'HP04464.IES'        FIXTURE WATTS:   75.0
  used in calculations:  LUMENS=  3150.  LIGHT LOSS FACTOR= 0.850
  luminous dimensions:  ACROSS= 0.18   ALONG= 1.20   HEIGHT= 0.00

  Catalog Number:  VS-042RS-A12-S1
     Test Number:  HP-04464

                 LUMINAIRE LOCATION       LUMINAIRE ORIENTATION
                  X        Y        Z     BEARING   TILT    CANT
         ---   ------- ------- -------   ------- ------- -------
          1      1.10     2.70     3.30      0.00     0.00     0.00
          2      3.10     2.70     3.30      0.00     0.00     0.00
          3      1.10     6.40     3.30      0.00     0.00     0.00
          4      3.10     6.40     3.30      0.00     0.00     0.00
          5      1.10    10.10     3.30      0.00     0.00     0.00
          6      3.10    10.10     3.30      0.00     0.00     0.00
```

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COORDINATES ARE METERS SCALE 1:75
ILLUMINANCE IS IN HORIZONTAL LUX.
TARGET PLANE AT Z = 0.9 METERS.
(* = LOCATION OF SINGLE LUMINAIRE)